U.S. AERO MEDICAL RESEARCH UNIT, DAYTON, OHIO. EQUIPMENT LABORATORY

OUTLINE OF COURSE OF INSTRUCTION IN HIGH ALTITUDE PHYSIOLOGY

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FOREWORD

The material presented in this outline is a condensation and epitome of the lectures presented to Air Corps and Medical Officers during the course in "high altitude physiology". This course of instruction was conducted at the Materiel Division, Wright Field, Dayton, Ohio, January - March, 1941, with the view of forming a cadre of officers capable of instructing the combat crews at their home stations in the use of their oxygen equipment, in the physiological alterations that occur or might occur at high altitude, and to correct the misconceptions that are prevalent.

The instructional material is in no sense a training manual or textbook but is intended to serve as a guide or as a source of information in outline form for those officers conducting training in high altitude flying. It is recommended that texts on aviation medicine, monographs, and special articles be consulted for more complete information.

INTRODUCTION

Man adjusts himself to his surroundings to a remarkable degree. The human body constantly makes adjustments for changes in external temperature, for varying amounts of physical activity, for motion in space, for postural changes in relation to gravity, for changing energy requirements, and, all too frequently, against the inroads of toxic agents and disease. Changes of blood flow in respiration, in activity of the sweat glands, in activity of the kidneys, in the ingestion of food, or in the desire for rest or physical activity are all employed to maintain the internal environment of the body within very narrow limits of fluctuation.

In aviation the demands upon the compensatory mechanisms of the body are numerous and of considerable magnitude. The environmental changes of greatest physiological significance involved in flight are:

1. Marked changes in barometric pressure.

2. Large temperature variations.

3. Movement at high speed in three dimensions.

4. The mechanical characteristics of the flying machine itself as an abode or media.

Aeronautical and mechanical science has advanced rapidly in the past decade resulting in the development of highly maneuverable airplanes that can cruise at four hundred miles an hour, climb a mile a minute, and operate effectively at thirty thousand feet or higher. It is obvious that man cannot operate these machines at full capacity without physical aids such as an artificial oxygen supply and pressurized equipment at extreme altitudes. Sharp turns or pullouts from dives at high speed cause centrifugal effects, many times the normal effect of gravity, leading to unconsciousness, if prolonged.

Flying personnel should not only know the capacity of their flying machines but should also know the limiting factors of inadequate adaptation of the human body. Captains of large aircraft command their crews and are responsible for the welfare of these men. Ignorance and carelessness can do much to nullify the care, ingenuity, and effort involved in supplying efficient equipment and can result in failure of missions or even in death.

For purposes of instruction of flying personnel in high altitude flight it is believed necessary for those conducting this training to have some grasp of the basic physiological facts regarding respiration, circulation, heat regulation, and gases of the blood.

Only by possessing such basic knowledge can they intelligently understand the alterations and symptoms occurring at high altitude and the precautionary measures to be taken.

It is believed that the scope of instruction at Tactical Stations will not be as inclusive as the material presented herein and that the teaching will have to be more didactic and dogmatic. It is obvious that the average man would have little direct interest in "acid-base balance" or even in the blood gases so it will fall upon the instructor to select his data and method of presentation.

TACTICAL CONSIDERATIONS OF HIGH ALTITUDE FLIGHT

The expression has been heard repeatedly that the present war in Europe is a "10,000 metre war". That may be something of an exaggeration, but it is indicative.

While in England we asked a number of pilots if they were doing high altitude work and how high this was. They claimed to be working regularly at high altitudes, but upon further questioning it was found that not very many flights were made above 20,000 feet. A good many of the airplanes had been so modified with increased armament and armor protection that 18,000 feet was about their practicable operating limit. But they were flying at this altitude and higher if possible. There is certainly a great willingness to go upstairs. Almost every day during the spring and summer of 1940 in England it was possible to trace overhead the paths of some individual reconnaissance planes. These were flying at great altitudes leaving cloud traces in the sky. Although these raids were all plotted with one airplane on a reconnaissance flight, it was apparently not worthwhile to send up a squadron of fighters to intercept it. Consequently, the individual reconnaissance planes operated all summer without interference. Before the French collapsed they were apparently doing the same thing. They were operating at high altitudes for security. How high they actually got, we don't know. In the last war pilots frequently flew at altitudes of 15,000 feet and apparently did considerable operating at around 18,000 feet. In telling about these more or less unusual flights, the general impression was created that all combat was conducted at 15 to 18,000 feet.

At present 10,000 metres is very high. Probably most flying is done actually between 15 and 20,000 feet. Some of you who have had the benefit of tactical school training are quite familiar with all the theoretic advantages of high altitude flight, particularly for bombardment. The bombers feel that at high altitude the possibility of interception is very much less. Certainly, if you increase the volume in which you are operating by increasing the vertical element, there is considerably greater freedom of operation. It is not only more nearly possible to carry on operations without being detected, but if detected, the interception itself is much more difficult. The pursuit planes which are supposed to catch the bombers are going to try to get above their targets for greater freedom of operation and for the performance advantage in losing altitude during the pursuit. However, we are definitely limited by mechanical problems in the construction of the airplanes and physiological problems for the crews. Of the mechanical problems, here are a few: Supercharging isn't as simple as it sounds. We can build compressors quite readily to supply air at sea level pressure up to altitudes close to 40,000 feet. However, there are a lot of other things that enter in. One of these is the necessity for intercooling. The problem of cooling the air back down again after pressure is applied is a serious one. Large bombers can put in large enough cooling systems to bring the

temperature down even at high altitudes, but small airplanes are different since they lack the space for adequate intercoolers.

Although you can build and install the compressor, frequently you can't get the air cooled enough to run the engine satisfactorily at high power at high altitude. In addition it is possible that due to the conditions at high altitude, the engine itself won't function. Some high altitude planes have had to supercharge the crankcase and have supercharged all manner of things such as ignition systems and magnetos. Fuel tends to boil at high altitudes and there are definite fuel pressure troubles to be corrected. There may be, and frequently are, hydraulic system troubles connected with both high altitude and low temperature and the lubrication of all moving parts including controls becomes a serious problem at the low temperatures experienced at very high altitudes. There are, in fact, many problems, some known and some unknown, connected with operating at high altitude. Some of them can be solved by the use of pressure cabins. This basically is a tank which is kept at some reasonably low altitude inside while the outside is taken up to high altitude. This is primarily of advantage to the crews, however, until recently there has only been one airplane that lived its useful life built on this principal, and that is the Air Corps XC-35. All previous pressure cabin airplanes prior to this had blown up or had serious difficulties. At least one was found with the airplane wrecked and crew all dead. The trouble was probably caused by some relatively insignificant failure in the mechanism. In some experiments with pressure cockpits in this country there was a small tank for the pilot but troubles were experienced.

Vents failed to work and in some cases the pilot barely escaped with his life. The pressurized suit performing much the same function as a diver's suit, although partially successful, has not as yet offered a good solution. In fact, it is not a simple matter to get a good solution. All the weight going into such an airplane or the addition of pressure features is a penalty on performance. We have at the present time a number of commercial pressure cabins, the so-called sub-stratosphere airliners. The idea there is to keep the pressure inside the same as that at 8,000 or 10,000 feet while the airplane is actually at 15 or 20,000 feet. Here you are primarily applying pressure for comfort rather than safety. It is entirely possible that you might use a pressure cabin airplane for altitudes of less than 15,000 feet in both commercial and military operations in order to maintain comfort and crew efficiency by keeping the inside down to 5 to 8,000 feet while the outside may be from 12 to 15,000 feet. However, at the moment we are confronted with the larger problem of safety at very high altitude. This is a new wrinkle and we know very little about it. Six months ago it wouldn't have been far from the truth to say you could count on your fingers the number of people in this country who had been over 30,000 feet. Certainly those that had been could count on their fingers the number of times they had been above this altitude. Why 30,000 feet had to be a limit I don't know, but we had not done very much flying above 30,000 feet. We have had quite a bit of experience above 20,000 feet and a

great deal about 15 to 20,000 feet, but 30,000 feet seems to be the boundary beyond which there has not been much exploration. We are just getting into it now. Problems arise all the time as we gain more knowledge of the conditions. Tactical operations have sometimes assumed that pressurizing the cabins of bombers was going to solve all high altitude problems, but this is not the case. In fact, the pressure cabin operation itself involves risk and hazard in itself. Suppose we are going to use the pressurized bomber at 30,000 to 35,000 feet on a tactical mission. In Europe they are intercepting some planes at 30,000 feet and in several instances at 27,000 feet, so that we can expect that at least some of the high altitude planes are going to be intercepted. When an interception is made at 30,000 to 35,000 feet the pressure cabin airplane is considerably more vulnerable. There have been a lot of proposals for quick-sealing of leaks. If you have small bullet holes through the cabin, the actual leak is not serious and even these can be stopped by laying a flexible patch over the hole. However, if you have seen any of the holes made in airplane structures by the larger explosive shells you know that these leaks are going to be serious and will not be sealed by laying on of patches. Another thing may happen. Complete windows may be broken out so that the problem of operating in a damaged cabin is a real and serious one. Above 30,000 feet you are faced with the fact that you are about 15 to 20 minutes removed from safe living conditions. When an accident occurs you have to retreat to safety. If you are 50 miles out to sea you can get back in 15 minutes and are to all intents and purposes just the same distance from safety. You are definitely in trouble if anything happens. Although it is apparent when you are out to sea, it may not be so apparent when you leave safety in going to altitude. It is difficult to tell the difference between 15,000 and 30,000 feet but you are definitely about 15 minutes away from safety at 30,000 feet, and this is as bad as being 50 miles out to sea. The problem of getting back to safety involves the provision of certain essential life-saving equipment. In high altitude operation this must be in the form of oxygen supply. However, in the race for the successful solution of high altitude problems, the pressure cabin airplane offers the best possibilities. Oxygen alone is not the whole solution of the problem. There is also the factor of pressure. So far we have been considering primarily bomber operations, but when you come to the counter-irritant, the pursuit pilot is not necessarily forced to go through the same physical exercise nor be exposed for as long a time so that the solution in his case may be somewhat different. The pursuit pilot is sitting still with relatively small movements of his head and limbs. Therefore, you can expect that the pursuit pilot will be able to operate at higher altitudes with less provisions for pressure and oxygen than the bomber crew who must move about. At the same time if you choose to pressurize the pursuit airplane, being a much smaller container, and with fewer openings, you can correspondingly include pressure provisions for smaller expense in weight and performance.

Since the pursuit plane is definitely limited in fuel and hence its endurance at high altitude, and since the pursuit pilot is relatively inactive, pursuit needs somewhat less in the way of

altitude protection. If the bombers are operating for four or five hours, it is possible that the pursuit will be able to operate for 30 minutes or so at 30,000 feet without a pressure cabin. However, when you get above 30,000 feet in general operations, pursuit types may have to have pressure cabins, but it is a less urgent and complicated development for pursuit. If interceptions can be made at high altitude it may be that we are entering a region of diminishing returns and perhaps it will not prove worthwhile going to excessive altitudes. You certainly know, however, that you can't overlook the possibility of operating at high altitude, and we are definitely faced right now with high altitude flight and the solution of its problems.

If you have been flying up around 30,000 feet you know it is perfectly possible to operate up there without undue discomfort, provided you have the right oxygen supply and know what you are doing. On the other hand, there are factors probably not very well understood. One of these is exposure even at relatively low altitudes. As an illustration, while on a flight from Los Angeles to Wright Field in a B-18, we flew the first 1,000 miles at about 13,000 feet. After having been there for about three hours, we began to get cold in spite of the cabin heat. Sometime later we turned on the oxygen and a little later noticed that the cabin was warmer. Then having some other work to do we stopped the oxygen and the heater apparently went bad again. When we used oxygen again the heater worked so we started checking up and found we were quite comfortable when working on oxygen and quite cold without, although the heater was putting out the same amount all the time. After some hours we went up to 15,000 feet and spent between three and four hours at this altitude. All of you have made enough flights at 15,000 feet to know that it is perfectly possible to operate there without oxygen but we kept taking oxygen anyway, partially to keep warm. Having flown most of the night, we arrived at about 3:00 A.M. and should have been very tired after a flight of about 13 hours without sleep, but we were on our toes and quite alert, landing wasn't difficult and the airplane handled nicely. There were no peculiar reactions or sensations even after this exposure and we suffered much less fatigue than usual on similar flights. We attributed it entirely to the fact that we had been using oxygen most all of the time although the major portion of the flight was at relatively low altitude and this checks in with other experiences. I am quite prepared from my own point of view to recommend that if you have a flight to make involving something like six, seven or eight hours flying in which there is no need to go above 10,000 feet and although it could be made without oxygen it would be more satisfactory to fly at 12 to 15,000 feet with oxygen in order to reduce the fatigue element. In another case while flying the XP-38 across the country, I was on oxygen at about 20,000 feet for a total of about six hours. Although I cracked up at Mitchel Field due to mechanical trouble, I wasn't tired and I am sure that fatigue did not enter into the accident. As a matter of fact, we were still working on the airplane trying to dismantle it at 10:30 that night after a very long day. Although confronted with a lot of statements that I must have been tired, I could not

explain why that wasn't true. Later on, however, checking with a lot of other flights including the B-18 trip which I have just described, I realize now that operating at 20,000 feet with oxygen was probably much less of a strain than operating at altitudes of about 10,000 feet without oxygen because I was making up for all the oxygen deficiency, while if I had been at lower altitudes, I would have neglected to make up the deficiency. This is only intended to indicate that every flight to altitude brings to light some factor which is apparently new. Obviously, many of the unknown elements are known in some particular quarters, but the same knowledge has not been disseminated. We are all faced with the necessity of learning more about the region.

In spite of what may or may not develop in the future, the fact remains that at the present we are faced with the necessity for high altitude operations and I would like to leave you with a point of view. If you are 50 miles out to sea and an accident occurs, you are definitely in an unfriendly medium, at least 15 minutes away from relative safety, and if you are at 30,000 feet or above, you are likewise in a region where you can no longer live unless you are protected and you are probably 15 minutes away from safety here. You are faced with navigation in an unknown region and should attack it as you would attack the problem of navigating in any unknown region. When out of sight of land you need a navigator to guide you, and you learn by repeated flights and a careful training program the methods of operation under these conditions. This same thing is true in any of the other unknown regions connected with flight. For high altitude we have to have navigators who can tell us how to go safely into this region and how to get back safely. Just as we would move into an unknown land we need the best data available, and then progress by easy stages from the known into the unknown regions until we have the whole region pretty well charted and can operate safely. We are just now beginning to explore the unknown regions of high altitude. There are a number of people who have made dashes into it, but generally speaking there has been no extended operation in it. There is a tendency to scoff at the idea that the region is definitely unknown, and a tendency to assume that any strong-minded individual can get away with high altitude flight without all this knowledge and equipment. This may be a suitable attitude for an out-and-out explorer, but if we are to really settle the region, it is a responsibility of those of you who are now here to find out as much as you can, to get as much experience as you can, and by careful coordination to get enough data together so that the Air Corps and all aviators, as a matter of fact, can actually navigate and operate successfully in what is now still a great unknown. Thirty thousand feet may be a boundary; it is like moving out to sea starting with shallows and then gradually into deeper water. There probably is no definite margin, but there is a definite transition. Mechanically, the equipment can be built although it is not an easy job. It may not appear to pay suitable dividends for the investment involved, however, we will not know until considerable history has been obtained on this kind of operation. Physiologically, the aviator is faced with a great many more unknowns, and the exact

limit of endurance may not be known for sometime. The flight surgeons and research workers are in effect the navigators who are charting courses and marking dangerous obstacles. You are now on the threshold of this region, and your problem is to learn how to explore the rest of it safely.

THE PHYSICAL CHARACTERISTICS OF THE ATMOSPHERE

This is a slight review of basic facts connected with the atmosphere, facts that pilots are generally familiar with. These remarks are made to recall them to mind and to possibly amplify their consideration in the light of physiological problems. They deal mainly with pressure, temperature, humidity and oxygen content. In the interests of simplicity and at the risk of over-simplification a few facts are presented.

Air Corps equipment is now available which will operate satisfactorily to, say, 40,000 feet, granted satisfactory crew operation to such heights. There appear to be, however, certain problems not completely solved, before forceful routine operations may be carried on at such altitudes.

Aerodynamically, the performance of an airplane depends on the density and viscosity of the air in which it flies. These factors in turn depend on the temperature, pressure and humidity of the air, which vary from day to day and place to place. In order to eliminate these variables from discussions and calculations of airplane performance these latter are customarily considered in connection with an assumed "standard air". This "standard air" has been accepted internationally. It is quite logical to consider it as a basis for physiological discussions, and such is generally the case. In connection with physiological and engine operation considerations it is further necessary to seriously consider total oxygen content at various altitudes. In addition, considerations of the gas, carbon dioxide, are required when discussing respiratory action.

The "standard air" is characterized by having the following properties: Its temperature at sea level is 15°C. (59°F.) and is at a barometric pressure of 29.92" Hg (760 mm. Hg or 14.7#/). One pound of sea level air occupies 13.07 cu. ft. Temperature drops off from 15° at the rate of 2°C (1.985) (or 3.57°F) per 1000' increase in altitude until the standard stratosphere is reached at 35,000 feet (35,332 feet) and a temperature of -55°C (-67°F). Above this level the temperature is constant at this value. Having established this temperature variation, it is a matter of relatively simple mathematical calculation to establish the manner in which the pressure and density vary with altitude. These calculations consider the fact that the pressure and volume of the gases vary directly as the temperature, the fact that the pressure at any point in the air is a result of the mass of air above that point; or rather that the rate of drop in pressure from sea level is proportional to the rate at which air (measured as a mass) is left behind. (See following equations)

Standard air is considered to be perfectly dry. The actual variation from standard is of small effect aerodynamically; the maximum effect being a change in density of about 2% (decrease) with high relative humidity at high temperatures. However, the effect of water has well known meteorological effects and is further matter

of vital concern at high altitudes because of window frosting effects and the freezing of oxygen equipment. Because of its "soothing" effect on combustion rates in engine cylinders atmospheric humidity allows increased maximum specific engine power outputs.

The final equations involved are recorded here in the interests of completeness:

$$t^{\circ}C = 15^{\circ} - 1.985 \frac{h'}{1000}$$

$$\frac{P}{P} = (1-0.00689 \frac{h'\ 5.256)}{1000}$$

$$\frac{P}{P} = (1-0.00689 \frac{h'\ 4.256\ }{1000})$$

See NACA Report 218, Appendix pp 256 & 257)

However, at given values of manifold pressure and rpm, power is reduced due to the decreased mass of air passing through the cylinder in a given time when moisture is present. Under these conditions the mixture strength is increased. These angles are essentially the same as considerations of small increases in altitude on engine operation. Humidity naturally increases the rate of engine cooling under a given set of conditions.

For physiological considerations further notice of the rate at which pressure and temperature drop with altitude is desirable. It may be noted that the pressure drops to one-half its sea level value at 18,000 feet, to one-third at 27,500 feet, to one-quarter at 33,700 feet. As pressure is the factor determining the rate of absorption of oxygen by living bodies, these relationships are of vital concern to crews operating at altitude. The standard freezing point is 7,500 feet, while it is 20° below at 17,500 feet and 55° below at the "stratosphere" lower level of 35,000. Cold has a definite effect on the rate with which personnel utilize oxygen which will be covered in another discussion.

The altitude pressure tables (see figure 1) cover conditions existing in "standard air". For aerodynamic purposes air warmer than standard causes each "tape-line" altitude to be at a higher density altitude due to the rarification caused by the hot expanded air. Air colder than standard gives reverse effects. This means that summer flying at a given tape-line altitude is at higher altitudes as far as the airplane and engine are concerned, winter flying being at lower effective altitudes.

For considerations concerned with the measurement of tape-line altitude such as clearihg mountains on instruments and blind let-downs and the measurement of altitude for bombing; it should be pointed out that altimeters register pressure changes which, for a given change in tape-line altitude, is less in summer than in winter. In other words a given "indicated" summer time altitude gives greater terrain clearance and bombing altitude than in winter. Note that

this is on the dangerous side for terrain clearance considerations in winter time when weather is poorest. Issue computers give actual corrections involved to a certain degree of accuracy. It is to be noted that flights into low pressure areas, normally associated with a certain amount of weather, cause, at a constant tape-line altitude, an increase in altimeter reading; or, when constant altimeter indication is maintained in flight, lower and lower tape-line altitudes are maintained. These considerations call for resetting of altimeters from radio reports, especially when approaching areas of general storms; and the use of greater terrain clearance margins in winter time.

In regard to the important factor of percentage of oxygen and absolute oxygen content, recognized sources give the sea level oxygen volume percentage as 20.93%; with this value essentially unchanged at altitudes to 72,000 feet. As the percentage of oxygen present in the atmosphere remains constant the amount available is proportional to the air density, the rate of absorption by man being governed by the atmospheric pressure or, more specifically, by the partial pressure of the oxygen in the atmosphere.

For physiological, aerodynamic and engine considerations the rate of variation of the density variable should be pointed out. Density falls to one-half its sea level value at 22,000 feet; to one-third at 34,000 feet; to one-quarter at 40,000 feet. For these reasons large increases in speed at constant power are obtainable at altitude; drag being proportional to air density; speed at constant power increasing as the cube root of the density ratio. To maintain constant power at quite high altitudes internally supercharged engines must have rather enormous sea level capacities (that is, their sea level potential horse power may not be used in order that engine damage may be avoided.) At best, such engines now in existence drop off from rated power at about 17,000 feet. Turbo supercharged engines on the other hand need not have other than normal sea level capacities for given altitude ratings as the supercharger is used only as required. It is to be noted that density does not decrease as rapidly as pressure with altitude, the temperature drop tending to slow its rate of decrease.

In connection with window fogging and frosting considerations it may be mentioned that, assuming none of the cabin sea level air is lost in an ascent to altitude (zero ventilation) and neglecting the moisture breathed into the cabin by the crew, window frosting will take place soon after the altitude is reached at which the free air temperature equals the dew point at the place of take-off. The frosting intensity is a function of the moisture content of the sea level air. For a sea level temperature, dew point spread of 20°C, this gives a frosting level of 10,000 feet. Naturally, ventilation and exhaled moisture are potent factors, being controlled under normal operating conditions, so that it may be said that window fogging (or frosting if temperatures are below freezing) is usually encountered at altitudes in the neighborhood of 25,000 feet and above. Present solutions appear to be to increase cabin ventilation by keeping heaters and defrosters continuously open and to wear

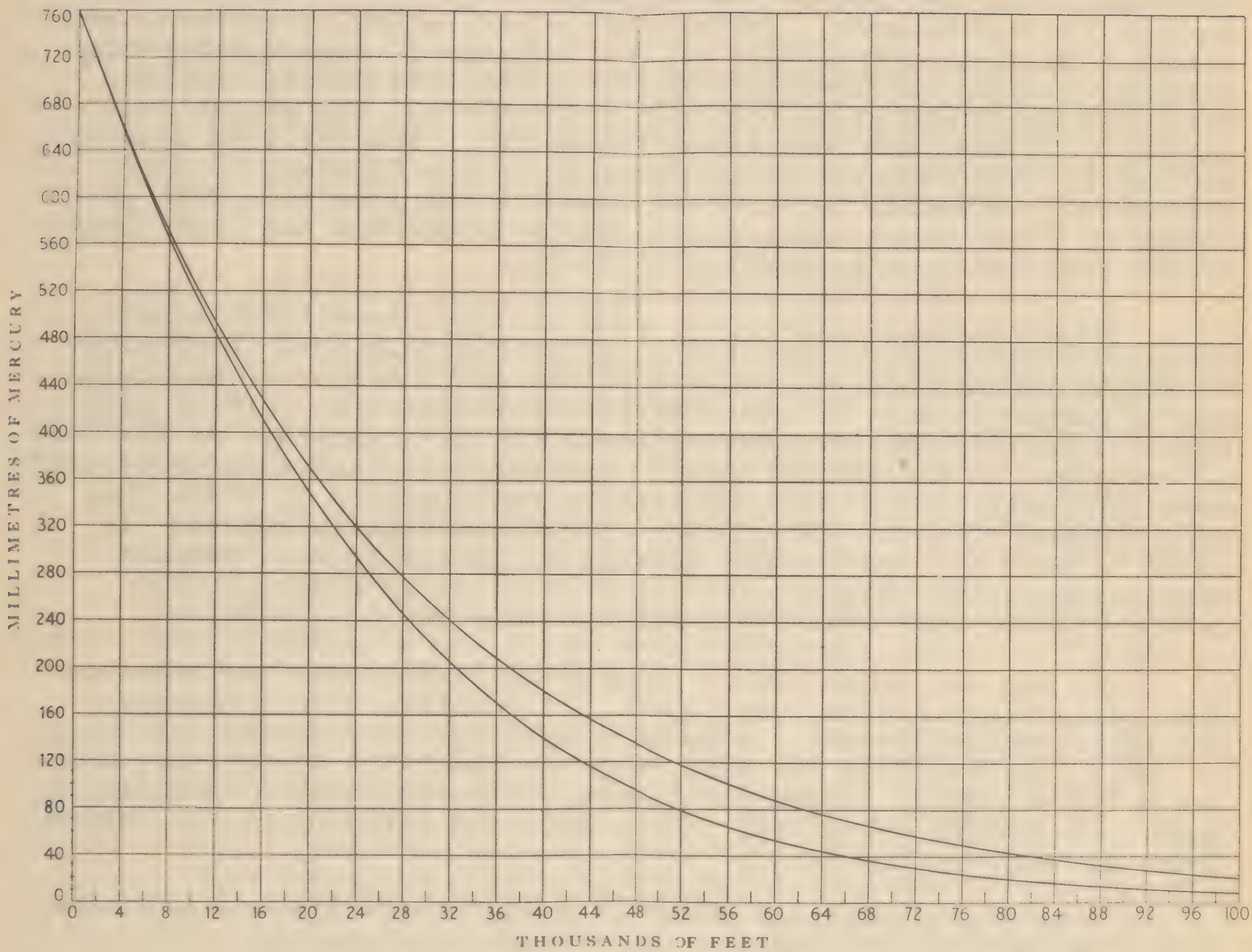
oxygen masks continually in order to avoid breathing directly toward windows and thereby causing the air adjacent thereto to become saturated; slight amounts of moisture being required therefore when temperatures are low. It is understood that frequent operations abroad are made with windows open to insure visibility causing great discomfort to the crews and even resulting in freezing injuries to personnel.

It is to be noted that the volume percentage of carbon dioxide is 0.03% at sea level and 0.02% at the bottom of the stratosphere. These percentages are totally insignificant in their effect on man.

In summary, the physical factors of the atmosphere of concern during altitude operations are pressure, in relation to air density, oxygen density, rate of oxygen absorption, and communication by voice; temperature as it controls air and oxygen density, as it effects crew comfort and ease of respiration, and as it controls dew points and window fogging and frosting and the freezing of equipment; mass oxygen content at various levels as it controls the amount of oxygen naturally available; moisture as it effects fogging, frosting and freezing.

Carbon dioxide and the rare gases are of no physiological significance in the atmosphere and the nitrogen, an inert gas, is only of significance in "bubble" formation in the blood ("bends") at very high altitude.

The air density is of some significance in communication at high altitude as one cannot whistle easily in the rarified air and speaking requires greater effort in air of low density.



Curves showing relation of barometric pressure to altitude.

The upper curve is calculated from the formula given by Zuntz, Loewy, Miller, and Caspari, assuming a mean temperature of 15°C. The lower curve is calculated according to the I.C.A.N. conventional law assuming standard conditions.

FIG. 1

THE PHYSIOLOGY OF RESPIRATION AND ITS RELATION TO FLYING AT HIGH ALTITUDES

Respiration is commonly called breathing. However, it may be more explicitly defined as the exchange of gases between an organism and its environment. In the case of all animal organisms, respiration consists principally of the exchange of oxygen and carbon dioxide. Oxygen is taken into the body and utilized to burn the food from which energy is derived to operate all the mechanisms necessary to keep the body alive and active. The oxidized gaseous product of this combustion, principally carbon dioxide, is then eliminated completing the process known as respiration. This exchange of gases takes place continuously throughout the life span of any organism from conception to death.

In microscopic organisms, such as the uni-cellular amoeba, the problem of respiration is a relatively simple one. Diffusion of oxygen through the cell membrane into the interior of the cell and of carbon dioxide to the exterior environment is sufficiently rapid to satisfy the respiratory needs of the organism. As the size of organisms in the animal kingdom increases it becomes progressively more difficult to meet the respiratory requirements of the animal by diffusion of gases through the general external surfaces. In order to meet the respiratory demands of larger animals complex respiratory system have evolved which will carry oxygen to and carbon dioxide away from every cell in the body of the animal.

In man and other higher animals we find one of the more complex respiratory systems developed. It consists of air passages and lungs, which present a tremendously large surface for diffusion of gases into and from the body, and the blood and circulatory system which serves as a transport system, carrying oxygen from the lungs to each and every cell in the body and carrying carbon dioxide from the cells to the lungs.

From a physiological point of view, respiration in the body of man may be divided into two classifications, namely:

1. Internal respiration, which has to do with the exchange of gases between the body tissue cells and the blood as the blood passes through the minute capillary blood vessels which permeate every tissue in the body.

2. External respiration, which has to do with the exchange of gases between the blood in the lung capillaries and the external atmospheric environment as represented by air in the air sacs of the lungs.

In the consideration of the subject of respiration as presented herein, we shall be concerned chiefly with the principles of external respiration. If oxygen in sufficient quantity and at an adequate partial pressure is supplied to the body via the lung air sacs, the blood and the circulatory system will accomplish the re-

mainder of the task, namely; the absorption of oxygen, and its carriage and distribution to all tissues in the body. The carriage of carbon dioxide by the blood from its point of production in all tissue cells to the lungs where it is eliminated is regulated automatically by certain centers in the brain and hence does not present any problems with which we need concern ourselves in this presentation.

Since the gaseous exchange of external respiration takes place in the lungs, it seems desirable, first, to understand the anatomy of the lungs and the physical and chemical principles involved in the exchange of gases therein before attempting to understand this phase of respiration in connection with the problems involved in flying at high altitudes.

Anatomy of the Lungs and Respiratory Tract

The lungs lie in the chest cavity much as a toy balloon might lie in a bottle (figure 2). As the air is pumped out through the opening shown in the bottom of the bottle, the balloon will expand until it flattens out everywhere close against the bottle wall. This is comparable to the lungs in the chest cavity.

Anatomically, the respiratory tract may be divided into the following parts:

1. The nose and nasal cavities through which the air first passes and within which it is warmed, moistened, and filtered of impurities such as dust.

2. The pharynx, larynx, trachea, large bronchi and small bronchioles which carry the air down into the lungs proper. The trachea and larger bronchi are partly surrounded by cartilaginous rings which make them semi-rigid. This rigidity decreases as the bronchi branch into bronchioles, the smaller bronchioles being quite elastic. The bronchi and bronchioles are lined with cilia, or tiny hairs, which serve to further purify the air entering the lungs. These cilia work in such a manner as to carry the impurities which collect on them to the top of the trachea, or wind pipe, where the impurities can either be coughed up or swallowed.

The final division of the respiratory tract, the alveoli or air sacs, is really the functionally important part of the respiratory tract, because it is here only that the exchange of gases between the body and the environment takes place. The relation of the alveoli to the bronchi and bronchioles is shown in Figure 2. Since the alveoli are the functionally important part of the respiratory tract, it seems necessary to consider them in more detail. Each alveolus, of which there are several million in the average human lung, is approximately 1/25 of an inch in diameter. The total surface area of all the alveoli in the human lung has been estimated to be between 700 and 800 square feet, which is 40 to 50 times the exterior skin surface of the body. The walls of these alveoli are moist and extremely thin, being only about 1/50,000 of

an inch in thickness. Each alveolus is surrounded by a network of capillary blood vessels through which blood flows at all times. It is the gaseous exchange between the blood in these capillaries and the air in the alveoli that is of utmost importance to the body. Although this exchange of gas must take place across two membranes, namely, the alveolar wall and the capillary wall, these membranes are so thin that they offer no material resistance to the transfer of gas. Actually, the blood remains in the lung capillaries only about one or two seconds, and it is in this short space of time that the necessary gaseous exchange occurs.

With this anatomical description of the respiratory tract in mind, we may now proceed to a consideration of the mechanics of respiration. The lungs remain expanded in the rigid chest cavity surrounded by the ribs on the sides and above, and by the diaphragm below. This chest cavity may be enlarged and the lungs inflated by raising the ribs and thus increasing the diameter of the cavity, and by lowering the diaphragm and thus increasing the length of the cavity. Both of these mechanisms are commonly employed in respiration. Expiration, under normal circumstances, is a more or less passive phenomenon which consists simply of relaxation of the muscles employed in inspiration. Under more strenuous conditons where more forceful respiration becomes necessary, expiratory muscles may be employed in expiration.

The average individual when at rest will expand the chest cavity at each inspiration to an extent which will draw into the lungs and respiratory passages about 500 c.c. (about one pint) of air. Approximately this same volume of air is expelled with each expiration. This process is then repeated about 12 to 16 times a minute in the average individual.

The volume of air inhaled and expelled with each breath is called the *tidal volume.* The tidal volume when multiplied by the number of breaths taken per minute will give the volume of air inhaled (and exhaled) per minute. The volume of air thus breathed per minute is termed the ventilation rate and in the average individual at rest amounts to 6 - 8 liters (500 c.c. x 12 - 16 breaths per minute = 6,000 - 8,000 c.c. = 6 - 8 liters per minute).

The volume of air which can be exhaled from the lungs after the deepest possible inhalation is termed *vital capacity* and represents the maximum value to which the tidal volume might be increased.

The tidal volume, ventilation rate and vital capacity may be conveniently measured on an apparatus called a spirometer. A diagram of such an instrument is shown in Figure 3. The soda lime shown in the diagram absorbs carbon dioxide from the expired air. The kymograph pen records the up and down movement of the spirometer bell on a revolving drum thus giving a record of the rate and depth of respiration.

Of the 500 c.c. tidal volume taken into the respiratory system with each inspiration the last 140 or 150 c.c. never comes into

contact with the alveoli or air sacs, this being the volume of air necessary to fill the respiratory passages leading from the nose to the air sacs. It is the first air to emerge on exhalation and if analyzed, its gaseous composition is found not to have been altered from that of outside air. Since this air has no gaseous interchange with the air in the alveoli, it is called "dead space" air. The remainder of the tidal air (350 c.c.) mixes with the air in the alveoli and emerges from the lungs upon exhalation containing approximately the same gaseous composition as air in the alveoli. It contains approximately 5.5 per cent carbon dioxide and 14.5 per cent oxygen. If this 350 c.c. is mixed with the 150 c.c. of "dead space" air, we obtain 500 c.c. of exhaled air per breath which contains about 4 per cent carbon dioxide and 16 per cent oxygen.

THE CONTROL OF RESPIRATION

It is apparent in the discussion of the functional divisions of the respiratory system just completed that the ventilation rate may be altered either by increasing or decreasing the tidal volume or by increasing or decreasing the number of breaths taken per minute. Normally both tidal volume and respiration rate (breaths per minute) increase or decrease together, the ventilation rate being rather delicately adjusted to meet the requirements of the body under most conditions at ground level. In order to understand the limitations of these adjustments it is necessary to first understand the mechanisms by which they are controlled.

A. Voluntary Control of Respiration

It is possible by conscious effort to increase or decrease the ventilation rate to a certain extent for short periods of time. This naturally upsets the equilibrium which is ordinarily maintained by the involuntary control mechanism (to be discussed shortly). However, as soon as voluntary control is relaxed the involuntary control mechanism readjusts the equilibrium to normal. For example, if one breathes deeply and rapidly for a few seconds at rest (called over-ventilation) the carbon dioxide content of alveolar air (air in the lung air sacs) will be reduced below 5.5 per cent and the oxygen content raised above 14.5 per cent. As soon as voluntary control is relaxed, the involuntary control mechanism takes over and automatically restores the normal equilibrium by decreasing the ventilation rate.

Since voluntary control plays no part in the ordinary control of the ventilation rate, being seldom imposed on the body, it is of much less importance in the present discussion than is the involuntary control.

B. Involuntary Control of Respiration

1. The Respiratory Center

The nerve impulses or stimuli which activate the muscles of the chest and the diaphragm and thus control the rate and

depth of respiration come from the respiratory center in the brain. It is only through alterations in these impulses that changes in the ventilation rate are produced. Such alterations are produced by (1) changes in the character of nerve impulses arriving at the respiratory center from various control stations lying outside the brain and (2) by changes in the chemical composition of the blood flowing through the respiratory center.

The most influential factor which affects the respiratory center is the chemical compostion of the blood supply to the respiratory center. This center is particularly sensitive to the carbon dioxide content of its blood supply. If the carbon dioxide content is a little high the respiratory center responds by increasing the ventilation rate until the carbon dioxide content returns to normal. This adjustment is quite delicate and as a result the carbon dioxide content of blood under ordinary conditions at rest is maintained within very narrow limits.

The respiratory center and respiratory control mechanism as a whole is not, however, very sensitive to lack of oxygen in the blood as is indicated by the fact that a moderate degree of anoxia, or oxygen lack, may exist without an immediate adjustment of the ventilation rate by the respiratory center.

The relative sensitivity of the respiratory control mechanisms to the two conditions, viz. carbon dioxide excess and oxygen lack, may be seen in Figure 4. Both parts of this figure represent respiratory tracings made when breathing back and forth from and into a spirometer (figure 3).

In the top tracing the spirometer was filled with an oxygen-rich mixture so that adequate oxygen was available to the subject throughout the test even though he used up some oxygen as the test progressed. In this tracing, however, the carbon dioxide absorber was removed from the spirometer and hence the carbon dioxide content of the spirometer air increased as carbon dioxide was eliminated from the body. As the carbon dioxide content of the spirometer air increased the carbon dioxide content of alveolar air and of the blood would likewise increase. The response of the respiratory control mechanism to this carbon dioxide increase is obvious, a marked increase in the ventilation rate being noted in the tracings. This represents the effort made by the system to maintain a normal carbon dioxide content in the blood and lung alveoli.

In the bottom tracing the spirometer was filled with a mixture of 20.9 per cent oxygen and 79.1 per cent nitrogen. As the subject used up the oxygen the per cent of oxygen in the mixture became less and less until a severe anoxia was produced in the subject when the oxygen in the spirometer was reduced to 6.1 per cent. The subject collapsed at the end of the tracing. The carbon dioxide absorber was placed in the spirometer to absorb all carbon dioxide

exhaled and thus eliminate the effects which carbon dioxide will produce on the respiratory control mechanism as observed in the upper tracing. The sole activating agent in this experiment was anoxia or lack of sufficient oxygen and it can be noted by the tracing that anoxia produced only a very slight effect upon the respiratory control mechanism as evidenced by a very small change in the respiration rate beginning at about the sixth minute.

Now at ground level this relative insensitivity of the respiratory control mechanism to anoxia imposes no undue hardship on the body under ordinary circumstances because as the need for oxygen in the body cells increases (for example, in exercise or work), the output of carbon dioxide by the cells likewise increases. The amount of carbon dioxide carried by the blood is increased, the respiratory control mechanism is stimulated, and the ventilation rate is increased to accomplish the elimination of the carbon dioxide. The increased ventilation rate increases the amount of oxygen brought into the lung alveoli and thus made available for absorption by the blood, but it is only because of the close parallelism between the rate of carbon dioxide production and the need for oxygen by the body tissues that the oxygen requirement is so well met at ground level.

At higher altitudes the situation is quite different. Here a given ventilation rate will result in the elimination of approximately the same amount of carbon dioxide as at ground level, but due to the decreased amount of oxygen in a given volume of air as the atmosphere becomes rarified, the same ventilation rate will not make the same amount of oxygen available for absorption by the blood. Thus an aviator at altitudes above 10,000 feet may suffer from lack of oxygen without any appreciable increase in his ventilation rate and without the slightest awareness of his anoxic condition.

It is because of this inability of the body to distinguish and interpret an anoxic condition that anoxia is so insidious, and insistance upon the use of oxygen is required of the flyer at altitudes where he personally cannot feel the necessity for its use and where the oxygen available in the atmosphere is not present in a sufficient concentration to meet the requirements of the body even if the need for oxygen could be detected.

Because of the nature of this problem and because of the necessity for flight up to altitudes as great as 30 or 40 thousand feet, it seems pertinent to discuss in detail the problem of respiration at all altitudes and the limitations imposed upon flight, with and without the use of oxygen, by the physical nature of the processes of respiration.

The amount of oxygen which is absorbed by the blood from the lung alveoli is dependent, among other things, upon the concentration of oxygen in the lung alveoli. This concentration is most conveniently expressed by the term oxygen partial pressure, the oxygen partial pressure being dependent upon the number of oxygen molecules per unit volume. At sea level the oxygen partial pressure in the lung alveoli equals about 106 mm. of mercury.

At this pressure the blood in passing through the lung capillaries becomes approximately 97% saturated with oxygen. As we climb or fly above sea level the total atmospheric pressure decreases and as a result the oxygen partial pressure in the alveoli likewise decreases bringing about a lessened oxygen saturation of the blood as it passes through the lungs. Due to the peculiar shape of the oxygen dissociation curve of blood (see Figure 10) the saturation of the blood is not greatly affected below the altitude of 10,000 feet. Going from sea level to 10,000 feet, the oxygen partial pressure in the alveoli drops from 106 mm. Hg to about 60 mm. Hg but the oxygen saturation of arterial blood drops only from 97% to 90%. However, with further decreases in oxygen partial pressure in the alveoli at altitudes above 10,000 feet, the oxygen saturation of the blood falls off rapidly and reaches 65 to 70% at 20,000 feet.

Figure 5 shows the pressure relationships which exist in the lung alveoli at various altitudes. Since the air in the alveoli is always saturated with water vapor at lung or body temperature (37°C), there is present in the alveoli at all altitudes a water vapor pressure of approximately 47 mm. of Hg. The respiratory control system being very sensitive to alterations in the concentration or partial pressure of carbon dioxide in the blood maintains approximately 40 mm. of Hg partial pressure of carbon dioxide in the alveoli at all altitudes. (In an anoxic condition this value may decrease to 35 or even 30 mm. of Hg but will be considered constant for the purpose of the present discussion.) The partial pressure of oxygen in the alveoli at sea level amounts to about 106 mm. of Hg. This value decreases (shown by the broken curve) with ascent to altitudes and consequent rarification of the atmosphere reaching a critical value at about 12,000 feet. The critical value shown represents a value below which mental and physical coordination are apt to be impaired and where the vital organs of the body (heart and brain) definitely begin to show deleterious effects. Consciousness may be maintained for a very short period of time with alveolar oxygen pressure as low as 25 mm. of Hg (attained at 25 to 28 thousand feet), but the ability of the individual to efficiently perform even quite simple tasks is lost after a few minutes' exposure.

In order to maintain a normal alveolar oxygen pressure at altitudes above sea level, it is necessary to enrich the inhaled air with oxygen. The higher the altitude the greater the enrichment necessary up to the altitude of 33,000 feet where the inhalation of absolutely pure oxygen is necessary in order to maintain a normal oxygen pressure in the alveoli.

Above 33,000 feet the total atmospheric pressure is not sufficiently great to enable one to maintain a normal oxygen pressure in the alveoli even when breathing pure oxygen, and the body must consequently suffer from anoxia (Figure 5). At 40,000 feet the critical oxygen pressure value in the lungs is reached. Above this altitude the body suffers from severe anoxia even when breathing pure oxygen, and unconsciousness would result at about 46,000 feet. Death would follow a prolonged exposure to higher altitudes.

In order to enrich the inhaled atmosphere with oxygen at altitudes and thus keep the alveolar oxygen pressure at a normal value, one must have a source of pure oxygen and a means of mixing this pure oxygen with the atmospheric air in such quantities as to bring about the increased oxygen per cent in the inspired air necessary to maintain normalcy at all altitudes up to 33,000 feet where 100% oxygen is needed. This result was attained formerly by holding between the teeth a tube or "pipe stem" from which oxygen flowed continuously in such quantities as to give the proper mixture when inhalation took place through the mouth. This method was extremely uneconomical because the flow was continuous and oxygen flowing out during all phases of the respiratory or breathing cycle other than the inspiratory phase was wasted completely. Also the flow had to be very rapid in order to obtain the proper proportion of oxygen to outside air in the short interval during which inspiration took place.

The administration of oxygen by means of a mask with a reservoir bag (Figure 14) is now replacing the above described tube or "pipe stem" method in the Army Air Corps. Although several designs of this mask have been tested and standardized for use, all of them embody essentially the following features:

1. Oxygen flows steadily into a collapsible bag or reservoir from which it can be drawn readily upon inhalation. This eliminates unnecessary waste or loss of oxygen during the expiratory phase since the oxygen merely collects in the bag for use at the next inhalation. This acts to decrease the rate of flow of oxygen necessary to obtain a given concentration or mixture in the inspired air.

2. The mask, bag, and valves are arranged so that the first air expired -- "dead space" air which has had no gaseous interchange in the lung and which is consequently rich in oxygen and contains little carbon dioxide -- returns to the bag and can consequently be used over again on the next inspiration, thus effecting a further economy of oxygen.

3. The last air expired -- being depleted of some oxygen and rich in carbon dioxide by virtue of admixture with alveolar air -- is eliminated from the mask system through a suitable expiratory valve.

The regulator to be used with the mask is calibrated to deliver at the indicated altitude a rate of flow of oxygen into the bag which will produce the proper mixture with atmospheric air to keep the alveolar oxygen partial pressure at the normal value of 106 mm. of Hg when the flyer is sitting at rest. If work, even in moderate amounts, has to be performed, the oxygen flow must be stepped up beyond that indicated at a given altitude in order to provide the increased oxygen needed.

The bag is of such a size that it will just about be completely collapsed by the normal inspiratory tidal volume of 500 c.c. When heavy work is performed and the tidal volume is greatly increased,

the flow into the bag must be increased to provide the additional inspired volume needed. This produces waste of oxygen during the respiratory phases other than inspiration but it is the only recourse available in the present mask to supply the additional oxygen needed during heavy work.

A "demand" regulator which will supply automatically any amount of excess oxygen needed during work is now in the process of development. This new regulator will permit an intermittent flow, making additional oxygen available during inspiration when it is needed and cutting off the additional flow during other phases of the respiratory phase when an additional flow of oxygen would simply be oxygen wasted.

SUMMARY

The respiratory system of man may be divided into the following principal divisions in accordance with their anatomy and function: (a) The nasal passages and tubes (trachea, bronchii and bronchioles) wherein the inspired air is warmed, moistened, and filtered of physical impurities, and through which outside air is conducted to and from the air sacs of the lungs; (b) the alveoli or air sacs of the lungs and their surrounding capillary network where the actual gaseous exchange of carbon dioxide and oxygen takes place between the body and its environment, and; (c) the blood and circulatory system in the body which acts as a transport system carrying oxygen from the lungs to all tissues and carbon dioxide from all body tissues to the lungs for elimination.

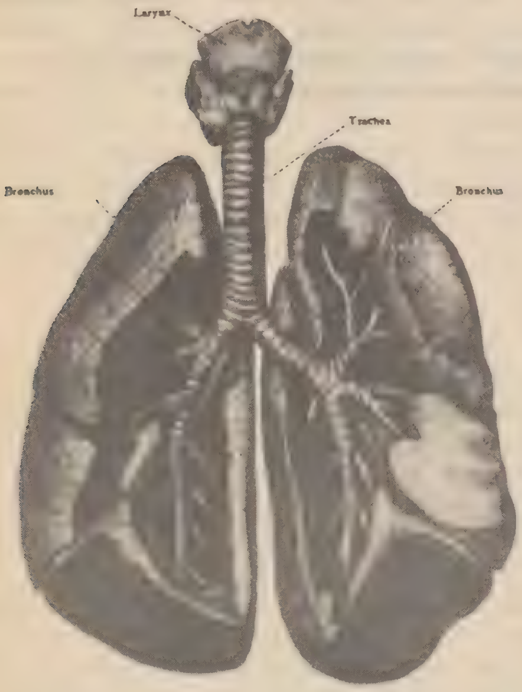
The volume of air breathed in and out of the lungs is controlled, involuntarily, by the respiratory center in the brain in accordance with the requirements of the body under almost all conditions at ground level. This respiratory control center is very sensitive to the carbon dioxide content of the blood but is relatively insensitive to oxygen deficiency in the blood. In the ascent to high altitudes the atmosphere becomes rarified and less oxygen is available to the body. But more serious is the fact that the body has no adequate mechanisms for recognizing or compensating for this inadequate oxygen supply. An aviator, when flying, for example, at 15,000 feet without a supplementary oxygen supply, may be entirely oblivious of the need of his body for more oxygen and would be unable to satisfy the need fully even if he were aware of it.

Consideration of the limitations which the decreased atmospheric pressures found at higher altitudes impose upon respiration in man show (1) the desirability for breathing oxygen enriched mixtures at altitudes between 10,000 and 15,000 feet and the necessity for doing so above 15,000 feet; (2) that the normal alveolar oxygen pressure cannot be maintained in the lungs at altitudes above 33,000 feet even when breathing pure oxygen; (3) that 40,000 feet is the absolute ceiling at which a pilot can be expected to carry out an operation with even moderate efficiency; and (4) that operations above 40,000 feet will require the use of some sort of pressure equipment by the airplane personnel.

The oxygen mask used at present by the Air Corps is capable of maintaining normal oxygen pressures in the lungs at all altitudes from sea level to 33,000 feet except in hard work. This mask is designed for economical utilization of oxygen at all altitudes commensurate with an adequate oxygen supply to the lungs of the aviator. Certain limitations to the use of the mask have been found and steps are being taken to obviate those that have been found incompatible with the efficient performance of airplane crew members.

ANATOMY OF THE RESPIRATORY TRACT

a.-Diagram of toy balloon in a bottle -- analogous to lung in chest cavity. If air is pumped out of bottle at A, the balloon will expand and fill the bottle due to higher atmospheric pressure inside the balloon.



b.-The lungs and lower respiratory tract as seen from the front. The lungs have been partially dissected to show the branches of the respiratory tree. (after Toldt).

c.-Median section through the head showing the nasal cavity with turbinates removed. Note volume and extent of cavity. (from Spalteholz).

d.-Median section through the head, neck and upper part of thorax. The respiratory tract from nose to trachea is indicated by the white line.(modified from Toldt).

e.- Showing the air sacs or alveoli of the human lungs on the terminal twigs of the air tubes or bronchioles. They have been overdistended by pressure and magnified about ten times.(from Toldt).

FIG. 2

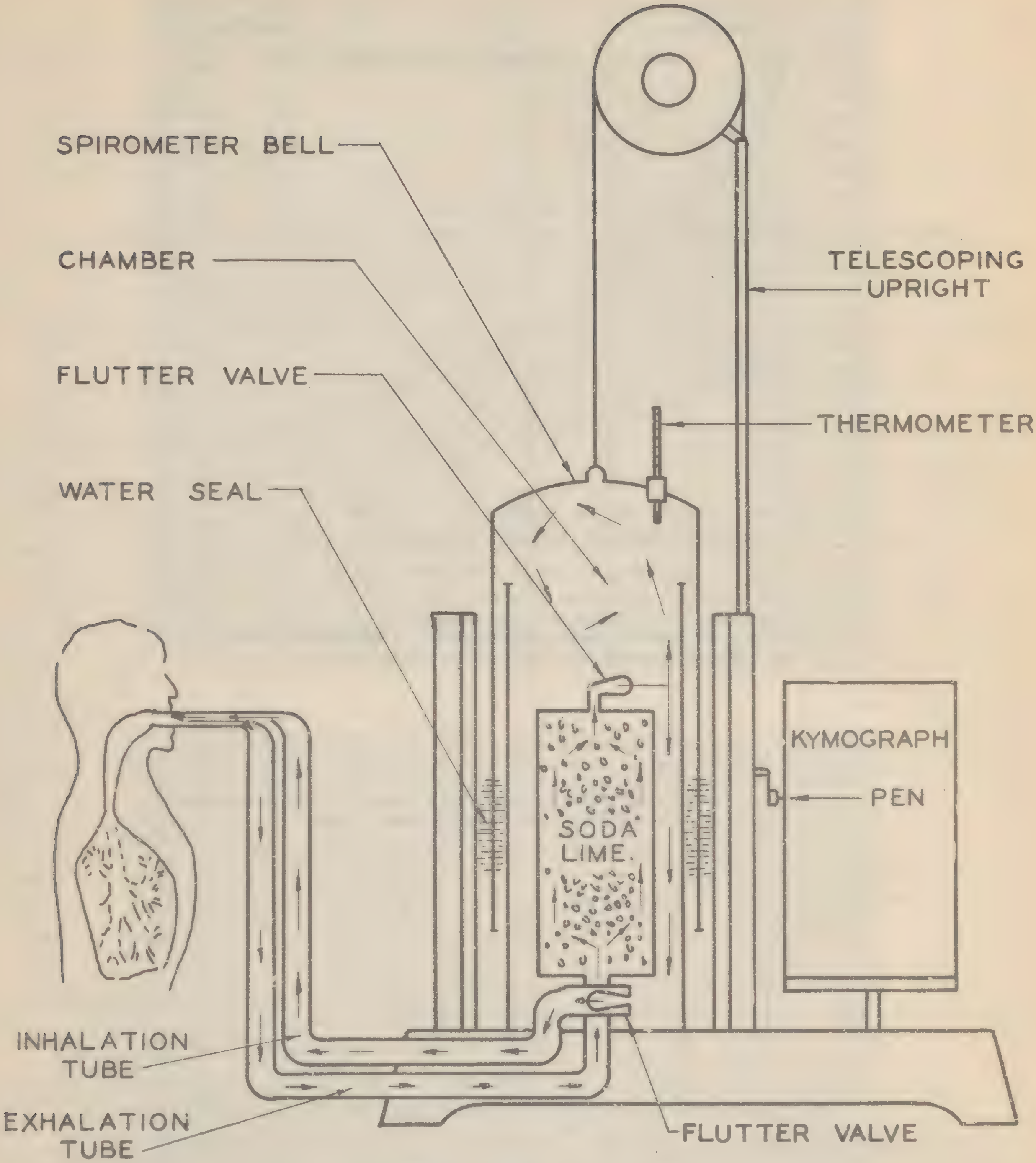
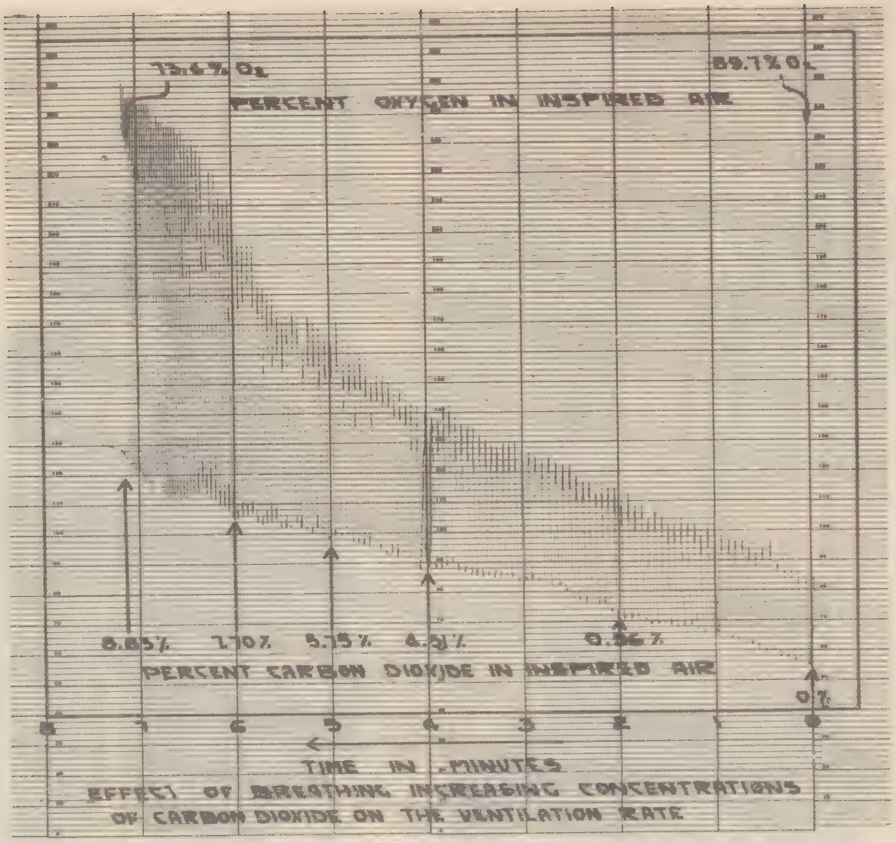
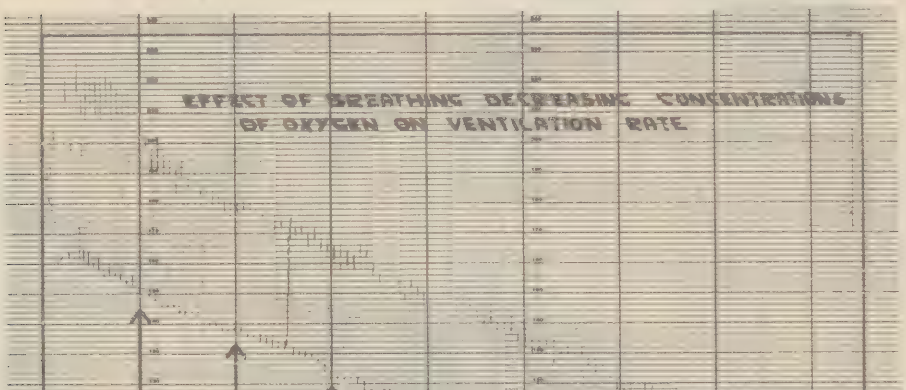


DIAGRAM SHOWING PRINCIPLE OF THE RECORDING SPIROMETER
(BENEDICT - ROTH PRINCIPLE. MODIFED FROM WIGGERS)

FIG. 3





THE RELATIVE SENSITIVITY OF THE RESPIRATORY CONTROL MECHANISM TO (1) CARBON DIOXIDE EXCESS (UPPER TRACING) AND (2) OXYGEN DEFICIENCY (LOWER TRACING). SEE TEXT FOR FURTHER EXPLANATION.

FIG. 4

ALTITUDE – PRESSURE CHART
SHOWING PRESSURE RELATIONS IN LUNG ALVEOLI AT VARIOUS ALTITUDES

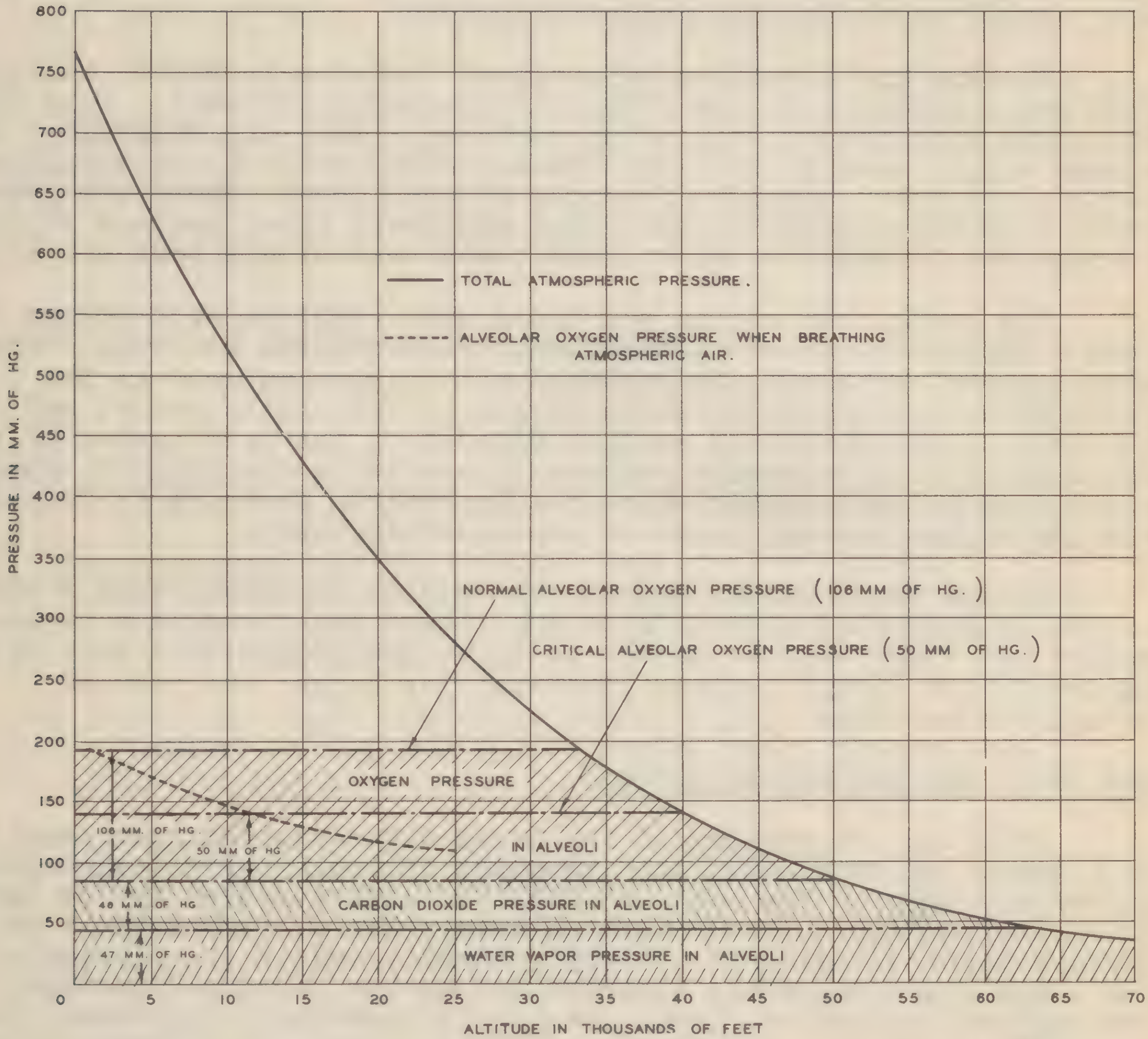


FIG. 5

THE CIRCULATORY SYSTEM

General Features and Functions

The primary function of a circulatory system is to supply all parts of the body with oxygen and food material, and to remove the waste products from tissue cells.

Blood, the circulatory fluid, consists of a fluid portion, the plasma, and a solid portion, the corpuscles or blood cells. In general blood contains a high percentage of water, several proteins, many salts, some fats and several pigments.

Perhaps the structure of greatest interest in blood, at least from the standpoint of the pilot, is the red blood cell. This is a biconcave disc-shaped cell which contains within its membrane a substance called hemoglobin (abbreviated as Hb) which is of vital importance in the transport of oxygen by the blood. There are great numbers of these cells in the blood and their total surface in the average man is equal to about 1500 times that of his body surface.

The hemoglobin of the red blood cell combines with oxygen to form a substance called oxyhemoglobin (abbreviated as HbO_2). The ease with which hemoglobin combines with oxygen as well as the facility with which it releases oxygen to the tissue cells, and the enormous oxygen absorbing surface offered by the vast number of red blood cells, are important factors in assisting the pilot to adapt himself to an environment where the barometric pressure is reduced, and the oxygen partial pressure consequently lower.

As the blood passes through the system of blood vessels the oxygen is gradually given off to the tissue cells and as a consequence the blood becomes darker in color due to the fact that the oxyhemoglobin (HbO_2) has now liberated its oxygen and reduced hemoglobin remains.

The Heart and the Way It Works

Briefly, the anatomy of the human circulatory system consists of a heart, or pump, and blood vessels, including arteries, capillaries and veins. The motor of the circulatory system is the heart which is, in fact, a two-chambered pump. Blood returns from the body by means of veins to the right chamber and is then pumped to the lungs where oxygen is absorbed and carbon dioxide liberated. It next passes to the left heart chamber from which it is pumped through the main arteries to the fine capillaries extending throughout the body. In the capillaries the oxygen from the blood is released to the tissue cells, and carbon dioxide from tissue cells is absorbed by the blood. The course or path of the circulation is schematically illustrated in Figure 6. The cardiac output or the amount of blood leaving the heart per unit time determines the circulation rate as well as the height of the blood pressure. In the normal resting man about 3 - 4 liters (quarts) of blood are pumped per minute by

each side of the heart.

The work performed by the heart is quite impressive. For a man at rest over a twenty-four hour period, the total work done amounts to about 72,000 foot-pounds and the heart beats or contracts approximately 100,000 times during such period, while in exercise this amount of work increases quite markedly.

Each contraction of the heart forces a volume of blood out into the large artery or aorta, resulting in a wave of increased pressure which passes over the arterial system at a velocity of from 20 to 30 feet per second and is termed the "pulse". In Figure 7 the mechanics involved in its production are illustrated. AB is a rigid tube filled with water and represents the heart. BC is an elastic tube analogous to the arterial system. The movement of the piston (analogous to the heart beat) results in the distention of the elastic tube by the forces as illustrated. Blood passes along the arterial pathway at a velocity of about one foot per second in rest, and as it does so the pulse gradually decreases, disappearing entirely in the capillaries, while in the veins the blood flow is steady or continuous.

The Regulation of the Heart and the Blood Vessels

In order that the heart's action be adapted to the body needs as a whole, it is subject to the control of certain brain centers and certain nerves so that its action may be either automatically increased or decreased. Furthermore, both arteries and veins are composed of elastic coats and muscle layer, and a contraction or relaxation of the latter layer can alter the diameter of the blood vessel, thus altering the blood flow. The tension exerted by the muscular coats of the blood vessels is regulated by means of nerve impulses originating in the brain and relayed to the blood vessel walls by means of numerous nerves.

The heart and blood vessels constantly adapt their function to meet the demands of the body such as those that occur during exercise or during exposure to low oxygen in aircraft flight.

Anoxia, or oxygen lack, has a marked effect upon the circulatory system. The mild to moderate stages of anoxia such as would develop in a person breathing atmospheric air at altitudes from 8,000 to 18,000 feet, generally produce an increase in heart rate and blood pressure. However, at altitudes in excess of 18,000 feet the anoxia progressively becomes more severe until eventually the nerve centers regulating the circulation of blood finally becomes depressed and the blood pressure falls.

Exercise

Any form of exercise or muscular activity requires that an extra supply of oxygen be furnished to the active tissues and also that the increased production of the oxidative by-products be steadily removed. To bring this about the circulatory system must

respond by an increased rate of blood flow.

More blood passes through the lungs, more air is breathed into and out of the lungs, and more oxygen is consumed by the tissue cells in work than during rest. In Figure 8 it may be observed that the lung ventilation, the blood flow through the lungs, and the oxygen consumption increase in proportion to the work done or exercise involved.

During periods of moderate work the oxygen consumption and circulation rate may increase five or six times over the resting level while for short periods of time during severe work much greater increases may occur, but the by-products of muscular activity such as lactic acid are produced at rates faster than they can be removed by oxidation or other means and the individual is said to have acquired an "oxygen debt" which is gradually paid off, however, when the individual stops exercise and rests.

SUMMARY

The circulatory system functions primarily to bring oxygen and food material to tissue cells and carry off their waste or by-products. Its pump, the heart, is so nervously regulated that its output may be altered to correspond with the bodily needs. Consequently in periods of stress or strain it works harder than during resting periods.

Mild or moderate anoxia (oxygen lack) causes an increase in heart rate and blood pressure, while severe anoxia results eventually in circulatory collapse.

In exercise where more oxygen is required much greater quantities of oxygen must be transported from lungs to tissue cells, the lung ventilation rate is greater and the rate of blood flowing through the lungs is correspondingly increased.

GENERAL FEATURES OF THE MAMMAL BLOOD CIRCULATION.

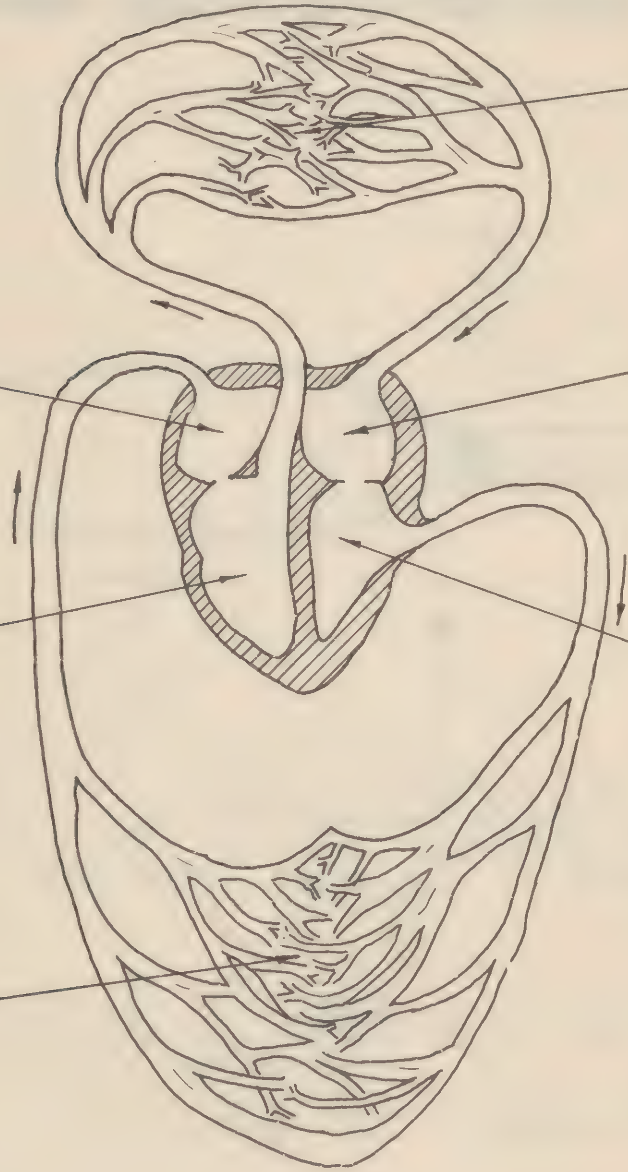


FIG. 6

DIAGRAM TO ILLUSTRATE THE PRODUCTION OF THE PULSE WAVE.

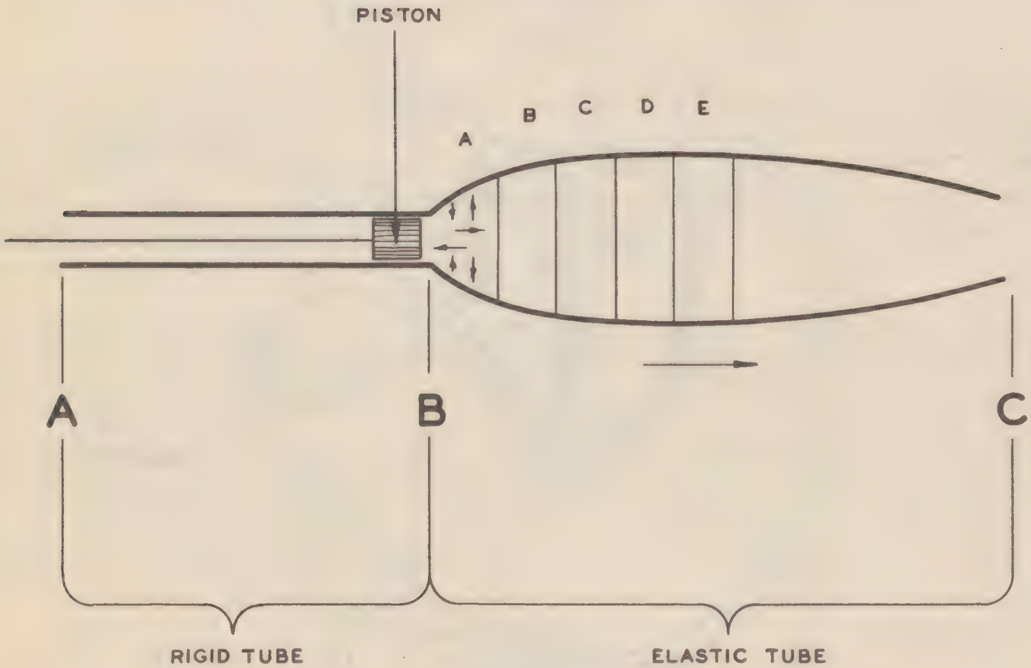


FIG. 7

EFFECT OF INCREASING AMOUNTS OF MUSCULAR WORK ON THE TOTAL VENTILATION OF THE LUNGS, THE BLOOD FLOW, AND ON OXYGEN ABSORPTION.

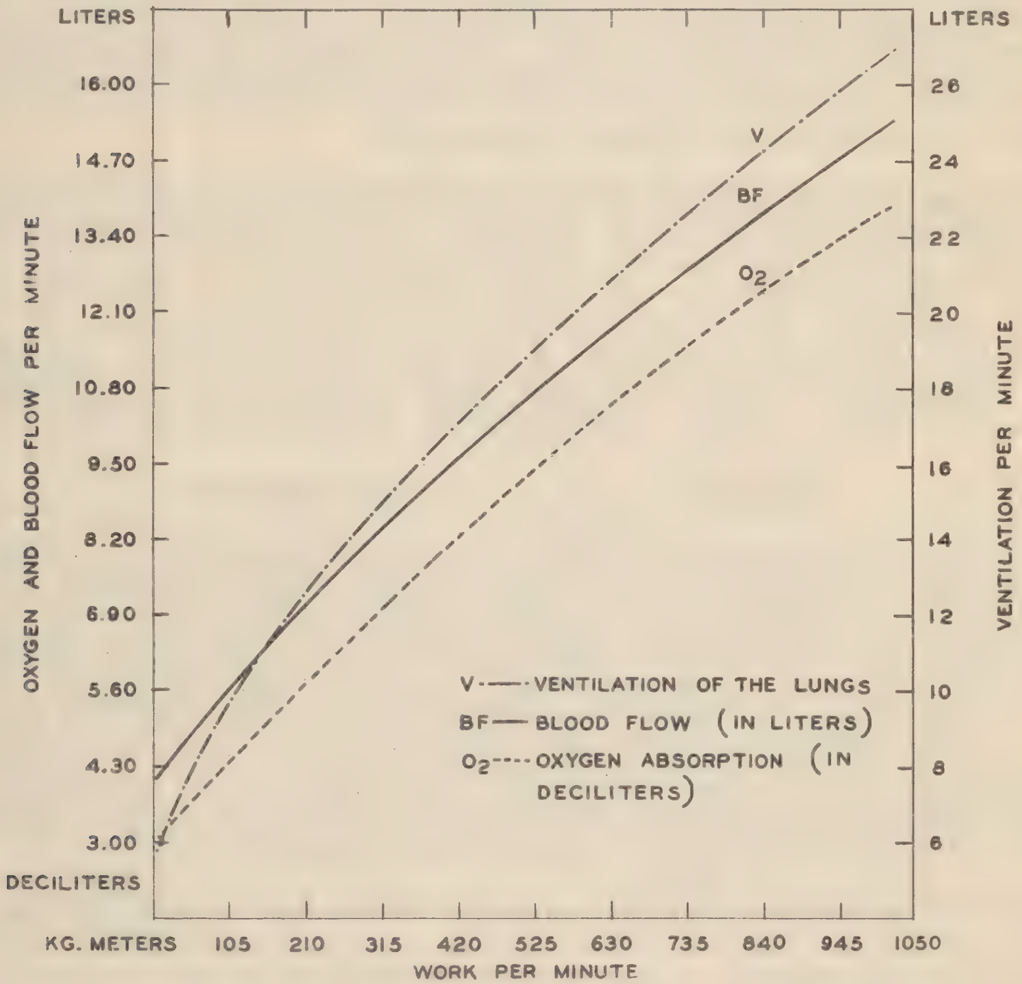


FIG. 8 (FROM MEANS AND NEWBURGH)

THE SIGNIFICANCE FOR THE PILOT OF THE OXYGEN PARTIAL PRESSURE, THE BLOOD GASES AND THE EXCHANGE OF GASES BETWEEN LUNGS AND BLOOD

The Oxygen Partial Pressure

In any mixture of gases, each gas will exert a partial pressure equal to that which it would exert if it occupied the entire space alone. Since the oxygen percentage in dry air at sea level is 20.93% by volume and since aside from water vapor the percentage composition of the atmosphere remains constant at all altitudes up to at least 72,000 feet as demonstrated by Capt. Stevens (1936) the partial pressure exerted by the oxygen (again neglecting water vapor) at any altitude will always be 20.93%, or roughly one-fifth, of the total barometric pressure. Figure 1 shows the relationship between altitude and barometric pressure.

The partial pressure of oxygen within the lungs, or the alveolar oxygen pressure as it is termed, is of practical importance, and in its determination the water vapor in the lungs must be considered. The air within the lungs (i.e. alveolar air) is completely saturated with water vapor at body temperature (37°C) and this vapor pressure amounts to 47.0 mm. of mercury at all times and at all altitudes. As an example, the calculation of the normal or sea-level alveolar oxygen pressure is illustrated below:

$$760 - 47.0 \text{ mm.} = 713 \text{ mm. mercury}$$

Accordingly, the pressure within the lungs exerted by oxygen, carbon dioxide, nitrogen and the rare gases, amounts to B - 47 mm. mercury where B corresponds to the existing barometric pressure. The <u>percentage</u> of oxygen in this mixture of gases that exists in the alveoli of the lungs has been found, on analysis, to average 14.5%. The oxygen partial pressure in the lungs, or the alveolar oxygen pressure then equals the percentage present in the lungs, multiplied by B - 47 mm. mercury. For example, at a sea level barometric pressure of 760 mm. mercury the alveolar oxygen pressure amounts to $(760 - 47)\,\frac{14.5}{100}$ or 103.0 mm. mercury.

As the alveolar oxygen pressure decreases the percentage oxygen saturation of the arterial blood also becomes less. Figure 9 illustrates the effect of breathing atmospheric air (21% oxygen) and of breathing oxygen (100%) at various altitudes upon the alveolar oxygen tension and the percentage oxygen saturation of arterial blood. It is to be observed that the use of oxygen greatly increases the pilot's range of performance, yet even while breathing pure oxygen the alveolar oxygen pressure, and particularly the arterial saturation, rapidly fall beyond an altitude of 35,000 feet. The limiting factor in altitude flying with oxygen equipment is therefore the alveolar oxygen pressure. When this falls below its normal value of about 103 mm. mercury the symptoms of anoxia begin to appear -- their severity depending upon the altitude reached and the

time spent at such altitudes. For humans the absolute limit for altitude flying with perfected oxygen equipment probably lies in the region of 45,000 - 47,000 feet.

Beyond an altitude of about 33,000 feet the alveolar oxygen pressure rapidly decreases even though the individual is breathing pure oxygen. As a consequence, the percentage saturation of the blood with oxygen falls. A deficiency of oxygen in the blood is called anoxemia, while the associated general lack of oxygen in the body is termed anoxia.

The Blood Gases

The blood gases of significance in respiration are oxygen and carbon dioxide. Nitrogen, while present in blood, takes no part in the respiratory exchange and is of importance chiefly in connection with the subject of aeroembolism, which is discussed in a subsequent lecture.

The respective concentration of the blood gases in the arterial and venous blood are illustrated in the following table:

Gas	Arterial Blood	Venous Blood
Oxygen	19.0 vols. %	13 vols. %
Carbon Dioxide	48 vols. %	53 vols. %
Nitrogen	1 - 2 vols. %	1 - 2 vols. %

The blood corpuscles contain within their membranes a substance, hemoglobin, which has the property of loosely combining with oxygen to form a substance, oxyhemoglobin, which readily can give up its oxygen to the tissues and again form hemoglobin. This substance, and its unique oxygen combining properties, are responsible for the facility with which oxygen is transported by the blood. In Figure 10 which shows the relation between the partial pressure of oxygen and the degree (per cent) to which blood is saturated with oxygen at such pressure, an important fact may be observed, namely, that blood holds a considerable amount of oxygen even at relatively low oxygen partial pressures. This is of great advantage to the pilot since it is only when the oxygen partial pressure becomes extremely low (i.e. the altitude is quite high) that the percentage oxygen saturation falls to critical or dangerous levels (60 - 70%).

The carbon dioxide produced in the tissues diffuses or passes into the blood where it reacts with water to form carbonic acid. This acid is neutralized almost completely by base supplied by hemoglobin and the carbon dioxide is thus transported in the form of bicarbonate. In the lung capillaries these processes are reversed and the gaseous carbon dioxide diffuses from the blood into the lung spaces.

The Gas Exchange Between the Lungs and Blood

The passage of oxygen from the lungs into the blood and carbon

dioxide from blood into lungs is initiated by differences in the partial pressures or tensions of the gases involved, since a gas tends to flow or diffuse always from a region of high pressure to a region of lower pressure. The average gas pressures (in terms of mm. mercury) existing in the lungs and blood at normal barometric pressure are outlined below:

	Carbon Dioxide	Oxygen
Alveolar air at sea level	40.0	103.0
Arterial blood	40.0	80 - 90
Venous Blood	46.0	40.0

Due to the above pressure differences oxygen passes from the alveolar air of the lungs into the blood and then from the pure or arterial blood into the tissues where the oxygen tension is lower. Carbon dioxide, on the other hand, passes from the tissues where its tension is relatively high into the blood which then becomes impure or venous blood. This blood upon reaching the lungs gives off a certain portion of its carbon dioxide since the pressure of carbon dioxide within the lungs is less than that of the venous blood returning to the lungs.

As the pilot ascends this gas exchange between lungs and blood is of course altered. First of all, the increase in altitude reduces the oxygen partial pressure -- this in turn reduces the alveolar or lung oxygen partial pressure. The presence within the lungs at all times of a constant water vapor pressure and of a carbon dioxide pressure that varies within relatively narrow limits considerably reduces the space available for oxygen. Consequently, the <u>alveolar</u> or <u>lung</u> oxygen partial pressure decreases during an ascent at a rate faster than the decrease of the oxygen partial pressure of the inspired air. When the <u>lung</u> or <u>alveolar</u> oxygen pressure falls sufficiently low, a point is reached where the amount of oxygen entering the blood (percentage saturation) begins to decrease, the end result being that the tension of oxygen in arterial blood is lowered and anoxia, or condition of oxygen lack, results.

During ascents, whether the pilot is breathing oxygen or atmospheric air, the alveolar or lung carbon dioxide pressure changes relatively little until altitudes are reached at which anoxia develops. This then results in an increased lung ventilation with resulting loss of carbon dioxide and a fall of alveolar carbon dioxide pressure.

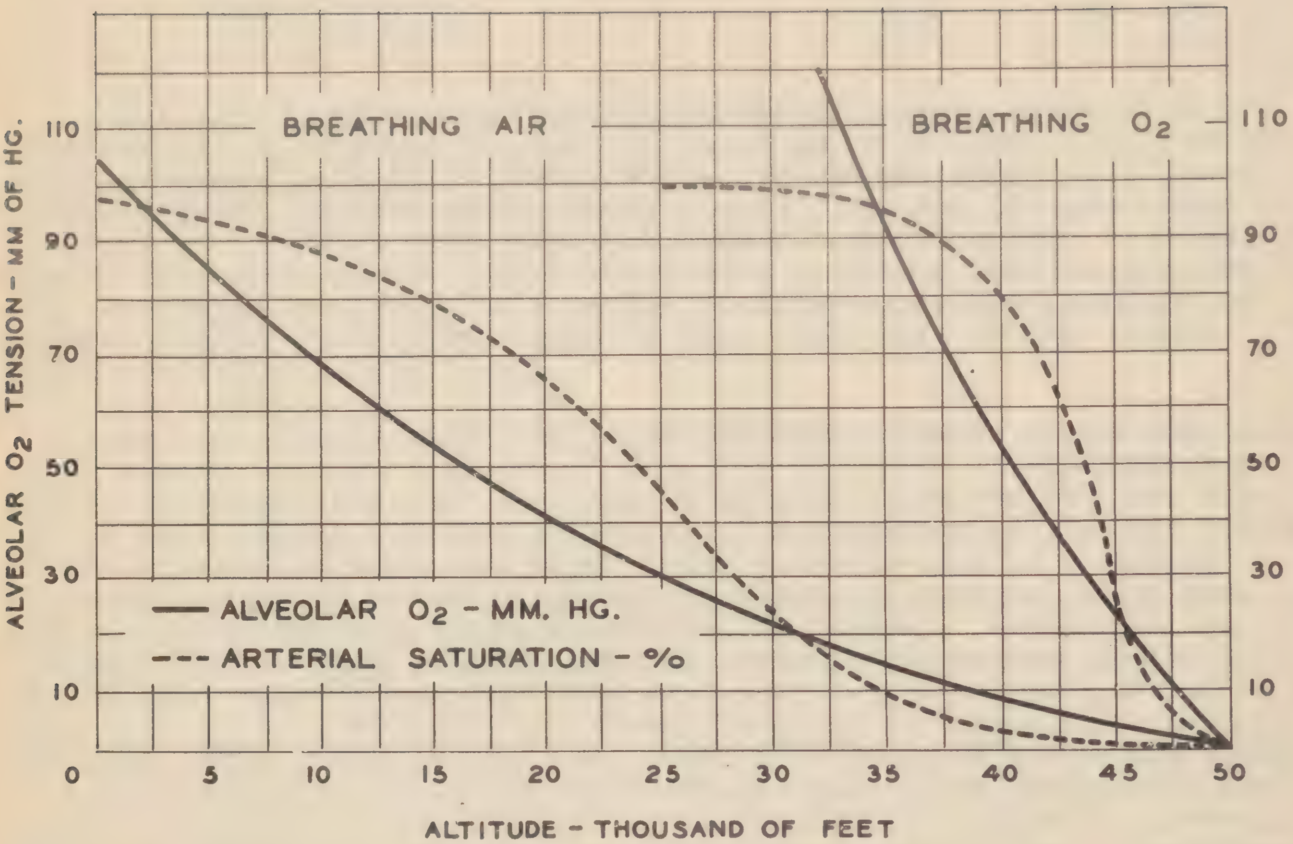
SUMMARY

The oxygen partial pressure in air is significant from the pilot's standpoint since upon it depends his lung oxygen partial pressure which in turn determines the amount of oxygen entering his blood. When the alveolar partial pressure is markedly reduced, the percentage saturation of the blood is lowered and anoxia occurs.

The transport of oxygen from lungs to tissues is performed chiefly by the substance hemoglobin contained in the red blood

corpuscles. While carbon dioxide is carried from the tissues to the lungs principally in the form of bicarbonate, the base supplied for this purpose comes chiefly from hemoglobin.

The gas exchange between lungs and blood is dependent upon pressure differences between gases within the lung and gases carried by the blood. As the pilot ascends, such gas exchanges occur normally until the alveolar oxygen pressure is markedly reduced and anoxia develops.



THE ALVEOLAR OXYGEN TENSION AND THE PERCENTAGE OXYGEN SATURATION OF THE ARTERIAL BLOOD CALCULATED AT VARIOUS ALTITUDES WHILE BREATHING ATMOSPHERIC AIR AND WHILE BREATHING OXYGEN.

FIG. 9

OXYGEN DISSOCIATION CURVE OF ARTERIAL BLOOD
(40 MM CO_2 PRESSURE)

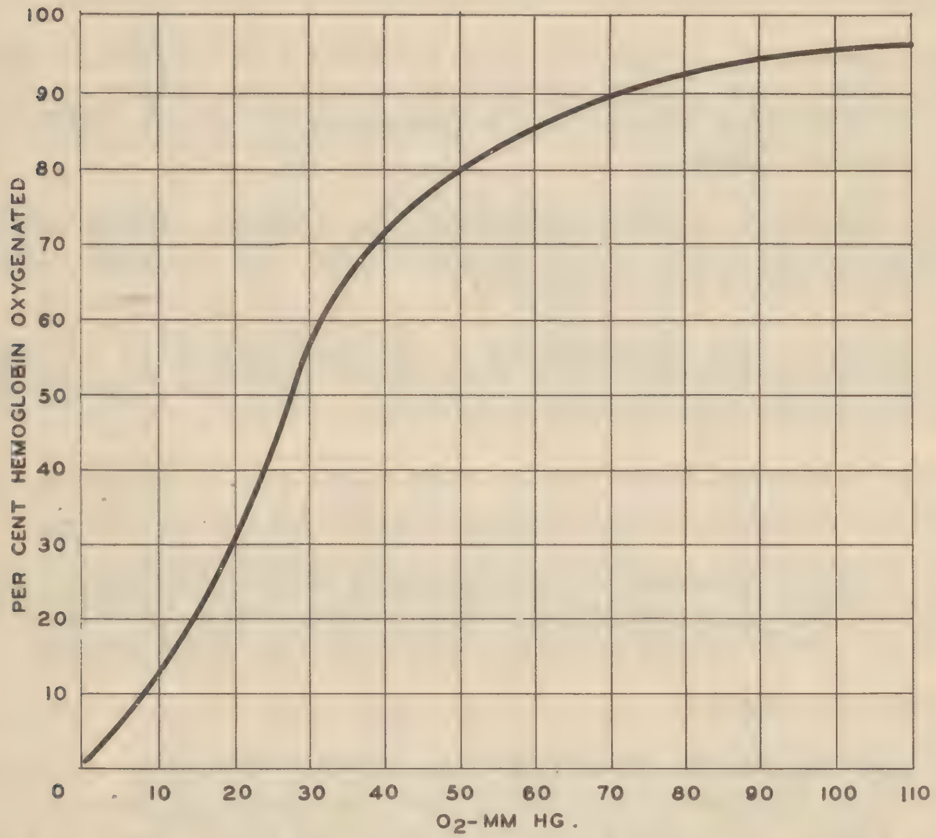


FIG. 10

OXYGEN EQUIPMENT

I. Among the earliest methods of dispensing oxygen at high altitudes was the use of liquid oxygen and liquid oxygen equipment. Very early, however, the use of liquid oxygen had to be abandoned in Military aviation due to the impracticability of storing large quantities of liquid oxygen for use at unpredictable moments. Liquid oxygen boils away continually, and as such, cannot be stored in the same manner in which the compressed gas can be stored.

II. Ever since the use of liquid oxygen was abandoned and up until the middle of 1939, the complete oxygen equipment consisted essentially of:

A. High pressure cylinders for storing the oxygen. These cylinders were light weight aircraft cylinders in which the oxygen was stored at a pressure of about 1800 lbs. per square inch.

B. High pressure oxygen fittings and lines. These lines conveyed the high pressure oxygen from the storage cylinders to the dispensing equipment.

C. A regulator for dispensing a metered quantity of oxygen to fliers at altitude. The regulator was the Type A-6 and was manually controlled.

D. A low pressure flexible rubber hose for conveying the oxygen from the regulator directly to the flier.

All of the above equipment has serious short-comings. These deficiencies and the manner in which they were remedied will constitute a large part of the remainder of this paper.

III. Development of Mask.

A. The low pressure flexible hose which conveyed the oxygen from the regulator to the flier is commonly known as the Pipe Stem. The Pipe Stem is nothing more than a rubber tube held in the mouth between the teeth. This method of administering oxygen is extremely unsatisfactory.

1. In the first place, oxygen poured continually into the mouth puffing up the cheeks and requiring that the mouth be held open, to allow excess oxygen to escape. Some pilots would "bite off" the oxygen. This consisted essentially of closing the teeth on the pipe stem at the end of every inhalation and thus stopping the flow of oxygen during exhalation. However, this procedure was detrimental to the oxygen regulator.

2. Holding the pipe stem in the mouth continually causes a great deal of slobbering with consequent annoyance and inconvenience.

3. In the event that the oxygen was cold, as it frequently was, the sensation caused by the oxygen pouring into the mouth out of the pipe stem was very much akin to that of holding an icicle in the mouth, and as such, was rather uncomfortable.

4. The use of the pipe stem necessitated mouth breathing. To breathe through the nose could be fatal at altitudes above 30,000 feet. Mouth breathing, of course, is undesirable inasmuch as the normal method of breathing is through the nose or through both the nose and the mouth.

5. There are cases on record where the pipe stem accidentally dropped out of the mouth of the flier, and before he could recover it his sensibilities were dulled. He was overcome by anoxia and passed out. In all cases on record the pilot was fortunate enough to come to at lower altitude to find his airplane plummeting to the ground completely out of control. In those cases where the pilot did not recover, there is, of course, no record. It only takes about thirty seconds to pass out at 30,000 feet if the flier continues to breathe atmospheric air not enriched by oxygen.

6. Above all, the pipe stem method of administering oxygen was extremely inefficient. A large amount of oxygen was wasted inasmuch as the body simply did not use it. This inefficient utilization of the oxygen had two serious consequences.

   a. For a long mission, the weight of oxygen equipment which was necessary to carry along was far too large, and as such, very objectionable. The largest of the high pressure cylinders, the Type E-1 cylinder, weighs over twenty pounds and was capable of supplying oxygen through the pipe stem for about two hours. Thus a B-17 carrying a crew of nine men and engaging in a short high altitude mission of about five hours, would require twenty-seven E-1 cylinders, 540 pounds of cylinders alone!

   b. The large flow of oxygen made necessary by the use of the pipe stem aggravated the freezing problem in the regulator. The expansion of the high pressure oxygen in the oxygen regulator causes a drop in temperature at the expansion valve, which sometimes leads to the freezing out

of the small quantity of moisture in the oxygen. A large flow of oxygen, which means the expansion of a large quantity of oxygen, aggravates this condition.

B. Type A-7 Oxygen Mask.

1. Description. The first type of oxygen mask, the Type A-7, was a nasal type mask constructed with a dipped rubber nasal cover containing two dependent rubber tubes around the mouth which terminate in a single supply tube below the chin. Attached to the end of the supply tube is a metal air regulator and exhalation valve. A rebreather bag, constructed with flexible rubber hose, is attached to the end of the air regulating valve. A short metal sleeve is provided on the air regulator to permit the attachment to the oxygen regulator by means of a supply hose.

2. This mask represented a considerable improvement over the use of the pipe stem, especially as regards efficiency. The principle of the mask is as follows:

   Oxygen enters the apparatus at the inlet and is delivered through a tube to the lower end of the reservoir re-breathing bag. It is then inhaled by the flier. The exhaled gases pass down into the bag. When the bag becomes distended with the mixture of expired air and incoming oxygen, the pressure thus produced causes the remaining portion of the exhaled gases to pass out through the exhalation valve and through the port holes contained in the metal air regulator of the mask. The expired air thus escaping is from the later part of the expiration and contains the most carbon dioxide and the least oxygen, whereas the expired air which passes into the bag first and contains the least carbon dioxide and the most oxygen is available for re-breathing, thereby helping to increase the efficiency of the apparatus. On the next inhalation, the mixed oxygen and expired gases are again drawn in and further admixed with atmospheric air entering through the port holes. Without a rebreather bag, all of the exhaled gases, the first portion of which is still relatively rich in oxygen, would pass out into the atmosphere and would be entirely wasted.

3. Though this mask removes most of the undesirable points described in regard to the pipe stem, it has short-comings of its own, which were early recognized.

   a. The port holes on the air regulator required manipulation and change at high altitude. Below 10,000 feet three port holes were left open;

from 10,000 to 20,000, two port holes; from 20,000 to 30,000 one; and above 30,000 feet all port holes were closed. This caused the flier to pay an excessive amount of attention to the mechanism of his mask. Furthermore, it was a very simple matter to become confused with regard to the direction in which the air regulator had to be turned in order to close or open the port holes since the flier could not actually see the port holes with the mask on his face.

b. At low temperatures, the moisture exhaled with the breath was certain to freeze up the exhalation valve and the metal air regulator so that it was impossible to change the setting of the port holes even if the flier desired to do so.

c. The mask was a nasal mask only. This made it necessary for the flier to breathe exclusively through the nose. Some people habitually breathe a little bit through the mouth also. In the event that the nasal passages were obstructed due to a cold, it would be impossible to use this type of mask. The mask only covered the nose, consequently the oxygen supply stopped whenever the flier talked, since he inhaled through his mouth while talking.

C. Type A-8 Oxygen Mask.

An improved type, the Type A-8, was soon developed.

1. Description. The Type A-8 oxygen mask is an oronasal type mask which also permits re-breathing of part of the oxygen expired from the lungs and respiratory passages. This mask consists of a rubber moulded nasal cover with a rigid case of phenolic compound which supports the mask and a turret-like protrusion containing a sponge rubber disc in front of the mouth. Attached to the base of the mask is a connector sleeve of phenolic compound to which is attached a flexible rubber re-breather bag provided with an oxygen intake tube. The end of the intake tube is equipped with an oxygen mask coupling fitting, which permits the mask apparatus to be readily attached, bayonet fashion, to the oxygen outlet. The oronasal feature and the sponge rubber disc represent the principal improvements of this type mask over the Type A-7.

2. The principle of the Type A-8 is essentially the same as that of the Type A-7, with the exception that there are no metal parts and the sponge rubber disc takes the place of the exhalation valve and the air regulating mechanism. As in the Type A-7, a mixture

of oxygen and previously exhaled gases are inhaled from the rubber reservoir bag. Upon exhalation the first part of the expired air passes into the bag and as soon as the bag becomes distended, the remaining gases pass out through the sponge rubber disc. Upon inhalation, first the gases are taken from the bag and when the bag is depleted an additional amount of air is drawn in from the atmosphere through the sponge rubber disc. Increasing the flow of oxygen at higher altitudes permits the flier to breathe a richer mixture of oxygen and lesser amounts of atmospheric air.

3. In this mask there are no port holes to manipulate and there is no danger of anoxia in the event the flier breathes through his mouth. The valve which is the sponge rubber disc does not freeze up as readily as the metal valve on the A-7 mask; but here again, this type mask has several short-comings, some of which are peculiar to it alone, and some of which are common to both types of masks.

   a. The principal difficulty is the inability to carry on interphone and radio conversation easily and distinctly. Some amount of conversation can be carried on through the sponge rubber disc, but the results are not good.

   b. Bombardiers have complained that the mask and especially the turret in front of the mouth interferes with the convenient use of the bomb sight.

   c. After an extended use at low temperatures, the spong rubber disc will freeze up solid, thus making it impossible to exhale or inhale through the sponge rubber disc. Even before actual freezing occurs, the sponge rubber disc will gather up a good deal of moisture. This, however, can easily be remedied by replacing the sponge rubber disc with a spare one or by simply squeezing out the moisture from the disc.

   d. The re-breather bag hanging down from the face piece of the mask sometimes interferes with the normal manipulation of the hands at the controls or other equipment, or the bag may become caught in other apparatus.

   e. The method of holding the mask to the face appears to be capable of improvement.

Except for the first difficulty, that pertaining to conversation, most of these short-comings represent

principally petty annoyances and can easily be tolerated by anybody exercising a bit of patience and forbearance.

D. The present standard mask is the Type A-8A, for the most part identical with the Type A-8, but containing just one change of importance. The inlet tube which formerly ran directly into the rubber bag and was suspended from the rubber bag is now connected to the phenolic connector piece, thereby greatly relieving excessive wear and tear on the rubber bag.

E. Mask Improvements Under Development. Many of the deficiencies in the Type A-8A mask can be removed and development is at present under way to do so.

1. A mask is being developed which incorporates a microphone inserted directly in the mask. This should very greatly improve the problem of communication and should remove all difficulties with regards to this matter.

2. At the same time, the unwieldly turret in front of the mouth will be removed, thus doing away with a large part of the interference which is now encountered when using the bomb sight.

3. A mask is being developed in which the re-breather bag and exhalation valve are both conveniently encased and placed beneath the clothing. A tube leads out from the clothing to which a flexible corrugated rubber hose is attached and leads to the face piece. This arrangement will prevent the freezing of the exhalation valve and will prevent the excessive collection of moisture both in the valve and in the rubber bag. At the same time it removes the rubber bag from its present location and places it where it cannot possibly interfere with any of the functions which must be carried on in military aircraft.

4. Different methods of suspending the mask and holding it to the face are being considered. Perhaps an overhead strap or a method whereby the mask is attached to the flying helmet will improve and provide a more satisfactory means of suspending the mask.

IV. Oxygen Regulators.

A. The Type A-6 oxygen regulator was used for dispensing oxygen in conjunction with the pipe stem. The instrument is divided into a back chamber and a front gauge compartment. Oxygen enters the back chamber from the supply tank under the control of a regulating valve. This valve is operated by a spring-restrained diaphragm through a toggle

link mechanism and automatically maintains a constant reduced pressure in this chamber of about 30 pounds per square inch throughout the wide operating pressure range of a standard high pressure supply cylinder. A relief valve is provided in the back cover to protect the mechanism from over-pressure in the event of failure in the regulating valve. From the back chamber the oxygen flows through a needle valve which is manually operated by a knob from the front of the instrument. From this point, a calibrated orifice meters the flow to the pipe stem. The flow indicator, which is a Bourdon tube pressure gauge indicates directly the pressure difference across the calibrated orifice and is calibrated to indicate the flow corresponding to this pressure difference. The dial is marked directly in altitudes for simplicity and the proper flow for any altitude under normal conditions is obtained when the pointer is set at the corresponding graduation by opening or closing the needle valve. The cylinder pressure indicator, also a Bourdon tube type, is connected directly to the line from the oxygen tank and shows the condition of the oxygen supply.

1. This regulator is intended primarily for use with the pipe stem, and as such, dispenses the large quantities of oxygen which are necessary in using the pipe stem. In using in this manner, the regulator should be set as marked.

2. There may be occasion, however, to use an oxygen mask with a Type A-6 oxygen regulator. Of course, the oxygen mask being much more efficient does not require the large quantity of oxygen that the pipe stem does. Therefore, when the Type A-6 oxygen regulator is used with an oxygen mask, it will suffice to set the regulator at the 20,000 feet altitude mark and leave it at that setting for all altitudes. It should be realized, however, that this is only a temporary expedient.

B. The Type A-8 Oxygen Regulator.

1. The Type A-8 regulator is very similar to the Type A-6. It is intended to be used with the mask only, and as such, the quantity of oxygen which it dispenses has been greatly reduced. This has been accomplished by decreasing the size of the calibrated orifice and by recalibrating the Bourdon pressure gauge. The Type A-8 regulator can be quickly distinguished from the A-6 regulator because the knob is distinctly marked "USE WITH MASK ONLY".

2. Since this regulator has been calibrated for use with the mask, it should never be used with a mouth piece or pipe stem and whenever used with a mask, it should

be set as marked.

3. The outlet of the regulator is equipped with an oxygen regulator coupling fitting which permits the mask apparatus to be readily attached, bayonet fashion, to the oxygen regulator.

C. Type A-9 oxygen regulator. Both the Type A-6 and the Type A-8 regulators are intended for use with high pressure oxygen supplies. In the discussion of cylinders below, the change from high pressure to low pressure will be described. The present use of low pressure oxygen cylinders has necessitated a regulator designed to operate on low pressure. This is the Type A-9 oxygen regulator. In all other respects, it is identical to the Type A-8 regulator. The only difference is that it is designed to operate on a maximum pressure of 500 pounds per square inch and a minimum pressure of 30 pounds per square inch.

D. All of the above types are for the most part satisfactory, but some deficiencies are evident as are various methods of improvement.

1. At low temperatures, some difficulty has been experienced with freezing at the expansion valve of the A-6 regulator. With the Type A-8 regulator the flow is smaller and the tendency to freeze is not as great. With the Type A-9 regulator, the tendency to freeze is still less. The drop in pressure with the Type A-9 regulator is only from a maximum of 500 pounds to approximately atmospheric pressure, whereas, in the other types the pressure drop is from a maximum of 1800 pounds per square inch. This small pressure drop at the expansion valve causes a much smaller drop in temperature and the danger of freezing out moisture in the oxygen is greatly decreased.

2. The regulators are manual types, and as such, require attention on the part of the flier. It would be highly desirable if the dispensing of oxygen were completely automatic and required no attention whatsoever from the airplane crew members.

3. At present there is one regulator for every station in the airplane. If this could be changed so that one or two regulators could do the job for the entire airplane, it would represent a decided advantage.

4. At any one altitude the regulator dispenses a continual and constant flow of oxygen. There is no provision made for supplying the flier momentarily with the larger quantities of oxygen which may be necessitated by indulging in some form of strenuous exercise. This could be a serious deficiency in combat.

E. Improvements under Development.

1. Automatic regulators have been developed which, without any attention on the part of personnel, dispense the proper quantities of oxygen at all altitudes. Several of these types are now out on service tests and might in the near future be incorporated in aircraft. The automatic regulators have a further advantage that one regulator, or two for safety, are capable of supplying all the personnel of the airplane with oxygen.

2. Another type of regulator under development is the demand type. The demand type regulator is one which supplies the flier with oxygen every time he inhales, supplies him as much as he demands, and then shuts off when he exhales. Such a regulator would take care of the momentarily larger requirements of individuals under conditions of stress and work.

V. Cylinders.

A. High pressure cylinders. The first types of oxygen cylinders used in aircraft for storing compressed oxygen were of the high pressure type, holding oxygen at a normal charge of 1800 pounds per square inch. These oxygen cylinders contain serious disadvantages which have been completely removed through the use of low pressure oxygen cylinders.

1. The very first difficulty encountered was that which is met with in servicing high pressure cylinders. The practice was to remove the cylinder from the airplane to take it to the filling place, and there charge it to a pressure of 1800 pounds per square inch directly from the commercial 220-cubic foot oxygen cylinders. Inasmuch as the commercial cylinders themselves are only charged to a pressure of 1800 to 2000 pounds per square inch, this was not a very simple or convenient matter. The process relied upon was to fill the aircraft cylinders successively from commercial cylinders in which the pressures varied from 500 pounds per square inch.all the way up to the full charging pressure of 1800 pounds per square inch. A tedious process! Another method was to use an oxygen compressor for charging the aircraft cylinders. In either case the charging was not as convenient as it could be, and not as convenient as it is today with the low pressure cylinders.

2. Even though the servicing problem was sufficient reason to change from high pressure to low pressure, the change was mandatory after the results of gun fire tests were available. When the standard high

pressure oxygen cylinder, charged with oxygen at a pressure as low as 1200 pounds per square inch, is punctured by a 30 calibre bullet, the steel around the entrance hole burns in the oxygen atmosphere yielding a short but extremely hot and long flame. Such a condition certainly constitutes a hazard. But even worse than this, when a charged high pressure oxygen cylinder is punctured by a 50 calibre bullet, the cylinder explodes into two parts with great violence and is capable of completely disabling the airplane. An oxygen cylinder placed in the tail of an old pursuit ship was hit with a 50 calibre bullet and the resulting explosion took off the entire tail. After these tests, there was no question concerning the change from high pressure oxygen to low pressure oxygen. It might be mentioned that since then it has been found possible to prevent the high pressure cylinder from exploding, though not from burning, by winding piano wire around the cylinder. This, however, increases the weight of the cylinders which is already high. The pressure cylinders enjoy definite superiority with respect to weight, with respect to ease of manufacture, with respect to simplicity, and especially with respect to servicing.

B. Low pressure oxygen cylinders.

1. The low pressure oxygen cylinders consist of two deep drawn stainless steel hemispherical cups welded together to make a complete cylinder. The normal operating pressure of the cylinders is 400 pounds per square inch and they can very safely be used up to pressures of 500 pounds per square inch. Each cylinder is hydrostatically tested to 700 lbs/sq.in. and one out of every lot of 100 or less is hydrostatically tested to a pressure of 1100 pounds per square inch. If the cylinder fails at this pressure, the whole lot is rejected. Thus it is obvious that these cylinders are safe at and above their working pressures. In the airplane all the low pressure supply cylinders are manifolded together. They are filled from a single filler valve located in some convenient location, usually in the skin of the airplane. To fill them it is only necessary to bring up to the airplane several commercial 220-cubic foot cylinders, plug into the filler valve, and charge up the airplane. The method is very similar to that of refueling the airplane. Each of the cylinders in the airplane is protected by means of check valves in the line. In the event that any one cylinder is punctured only the oxygen in that cylinder is lost and the rest of the cylinders in the manifold are unaffected.

2. Because these cylinders carry oxygen at much lower

pressure than the high pressure cylinders, they must be larger in size. However, there is sufficient room in the airplane to place the cylinders. The use of low pressure permits of a smaller wall thickness and far from being at a disadvantage with regards to weight, these cylinders are lighter per quantity of oxygen carried than the high pressure cylinders.

VI. Low pressure oxygen system.

A. To gather up the loose ends from the various items of equipment which have been described, let's summarize the present standard oxygen system. The low pressure system consists of the necessary number of cylinders manifolded together in the airplane and filled directly in the airplane from a single filler valve. All of the cylinders are protected by means of check valves. A single manifold line which is aluminum alloy tubing of 5/16 inch O.D. runs throughout the length of the airplane and branches off at each station. An oxygen regulator is installed at each station deriving its supply from the main manifold line. A person enters the ship with his own personal oxygen mask. At the 10,000 foot altitude he adjusts it to his face, plugs into the regulator, and adjusts the regulator in accordance with the altitude at which he is flying.

B. In the future it can be expected that in place of a regulator at each and every station, there will be an automatic regulator supplying the manifolding line with oxygen and there will be a simple outlet at each station to which the flier plugs in and pays no more attention to his oxygen supply.

C. One other development that can be expected is the demand regulator. Here again the flier will simply plug into the oxygen line, pay no more attention to his oxygen supply, and receive all the oxygen he needs.

VII. Ground Equipment. It has been mentioned that the cylinders are charged without removing them from the airplane. This, of course, necessitates ground equipment for servicing in the field.

A. At present there is available

1. A cart which holds two commercial 220-cubic foot oxygen cylinders.

2. A regulator which attaches to these cylinders and which regulates both the flow of oxygen while charging the airplane and the final pressure of oxygen in the aircraft cylinders.

3. Flexible tubing running from the ground regulator

to the filler valve in the airplane. The flexible tubing has an adapter at its end which plugs right into the filler valve. After the airplane is charged up, the adapter is released and the back flow of oxygen is checked.

The operation of charging up an airplane with oxygen is thus a very simple one.

B. Also under development is a cart which can be readily towed around and which is capable of holding four commercial cylinders and a drier, containing activated alumina as the drying agent. This cart will have a greater capacity, will be capable of charging up a B-17 with its full oxygen requirements, and will in the very same operation dry the oxygen, thus still further reducing the danger of freezing the oxygen equipment.

VIII. Portable Equipment. It is frequently necessary at high altitudes to move about the airplane for some reason or other. To do so without oxygen equipment might be fatal and therefore it is essential that some form of portable equipment be provided.

A. The standard portable equipment now available consists simply of a small high pressure cylinder to which is attached an oxygen regulator, and the whole is carried in a cloth bag slung around the neck. Such a piece of portable oxygen equipment can be readily assembled at almost any station.

B. In order to do away with high pressure equipment in all forms there is under development a portable oxygen cylinder for use at low pressures. This cylinder need have only a short duration since it will be possible to refill the cylinder from the aircraft oxygen supply line while in flight.

IX. "Bail-Out" Equipment. In the event that a person has to bail out of an airplane at high altitudes, it would be necessary to supply him with oxygen until he reached a lower altitude. For this purpose there is being developed a small cylinder with an attached mouth piece capable of supplying a parachutist with oxygen for that small interval of time during which he would need it.

X. Pressure Cabins. Pressure Suits.

A. One method of ascending to high altitudes without the use of oxygen equipment or of ascending to altitudes above 35,000 feet where even oxygen equipment is insufficient, is to supercharge the airplane cabin and maintain an atmospheric pressure in the cabin equivalent to that encountered at altitudes of 8,000 to 10,000 feet. Such planes have been developed for commercial airlines.

B. An alternative method is to completely enclose the flyers in suits and to increase the air pressure in the suits thus simulating lower altitudes.

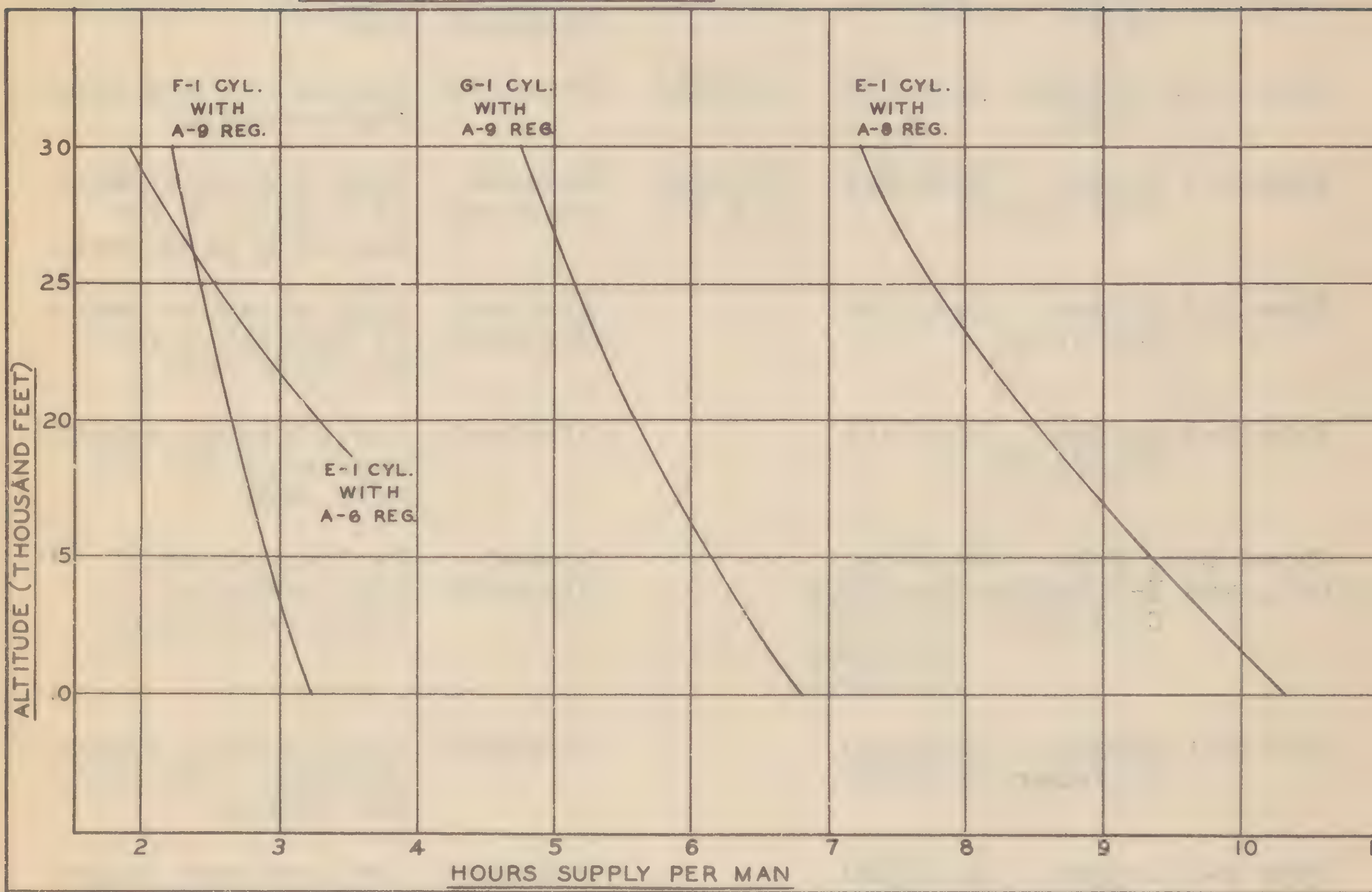
C. These two methods have the further advantage that they eliminate other physiological effects of high altitude flying. Both methods are receiving consideration.

TABLE I

STANDARD OXYGEN EQUIPMENT

Item	Spec.No.	Part No.	Status	Remarks
Type A-7 Oxygen Mask		40G2065	Limited Standard	Nasal rebreather Mask
Type A-8 Oxygen Mask	94-3107	40G6471	Limited Standard	Oronasal rebreather Mask
Type A-8A Oxygen Mask	94-3107A	41G5658	Standard	Similar to A-8 plus improvements
Type A-6 Oxygen Regulator	94-40249	Pioneer 962 C	Limited Standard	High pressure manual regulator for use with pipe stem
Type A-8 Oxygen Regulator	94-40300		Limited Standard	High pressure manual regulator for use with mask
Type A-9 Oxygen Regulator	94-40319		Standard	Low pressure manual regulator for use with mask
Types B-1, C-1, D-1, and E-1 Oxygen Cylinders	94-40244 94-40246 94-40247 94-40248 94-40251		Limted Standard	Various sizes of high pressure oxygen cylinders
Type F-1 Oxygen Cylinder	94-40320 94-40330		Standard	Low pressure oxygen cylinder 1000 cu. in. volume
Type G-1 Oxygen Cylinder	94-40320 94-40321		Standard	Low pressure oxygen cylinder, 2100 cu. in. volume
Aircraft oxygen cylinder recharger		41G5917		For recharging low pressure oxygen cylinders
Portable breathing oxygen apparatus		41Gs437	Standard	An assembly of standard items

HOURS OF OXYGEN SUPPLY



LEGEND

TYPE E-1 HIGH PRESSURE O_2 CYLINDER (1800 LBS. PER SQ. INCH).
TYPE F-1 LOW PRESSURE O_2 CYLINDER (350 LBS. PER SQ. INCH).
TYPE G-1 LOW PRESSURE O_2 CYLINDER (350 LBS. PER SQ. INCH).
TYPE A-6 O_2 REGULATOR FOR USE WITH HIGH PRESSURE CYLINDER AND PIPE STEM.
TYPE A-8 O_2 REGULATOR FOR USE WITH HIGH PRESSURE CYLINDER AND MASK.
TYPE A-9 O_2 REGULATOR FOR USE WITH LOW PRESSURE CYLINDER AND MASK.

FIG. 11

73603 Old oxygen apparatus. High pressure cylinder, Type A-6 regulator, and Pipe-stem.

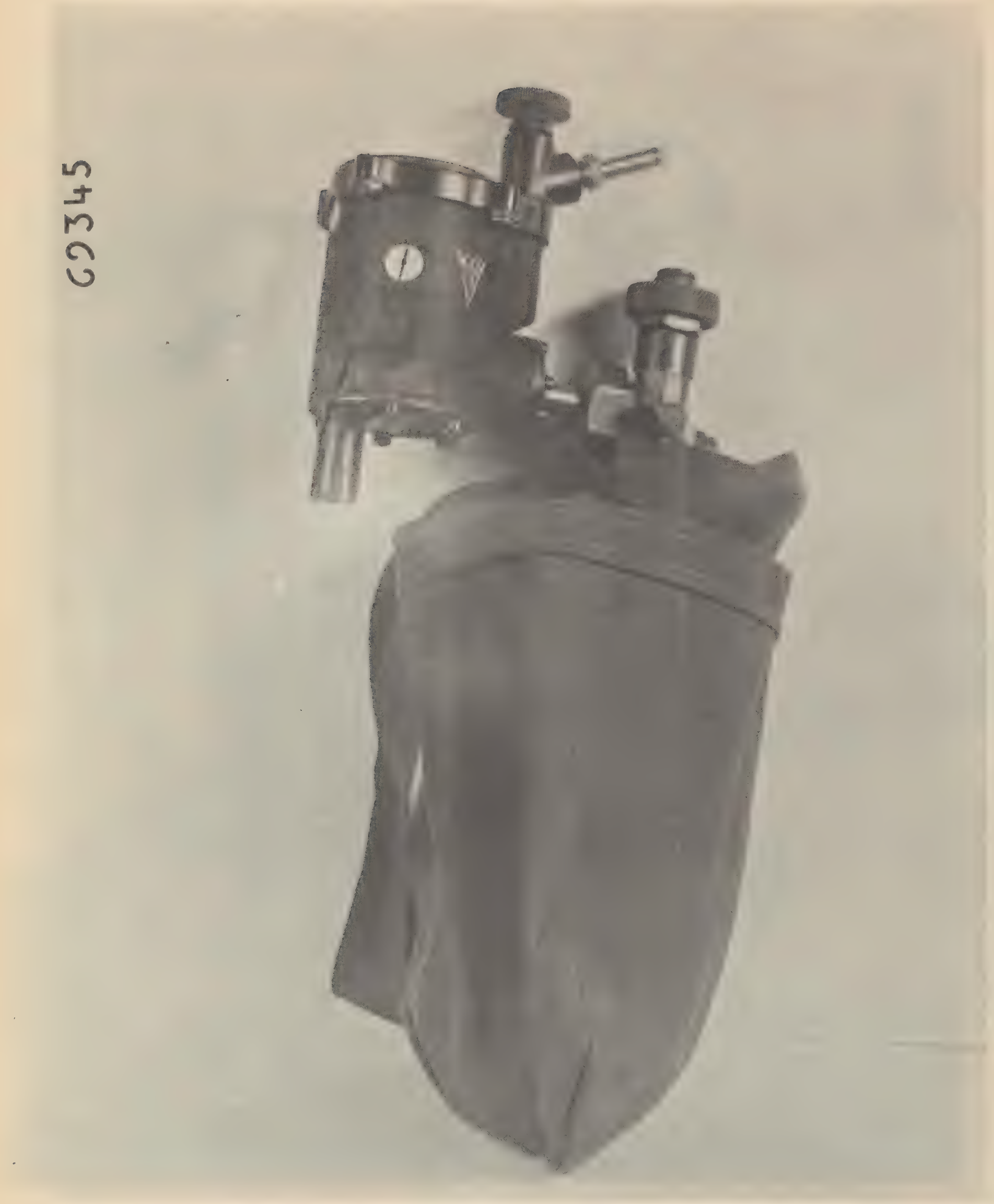
FIG. 12

73617 The Type A-8 oxygen regulator and Type A-8A oxygen mask show coupled together with bayonet connection.

FIG. 13

67603 The Type A-8 oxygen mask in use.

FIG. 14

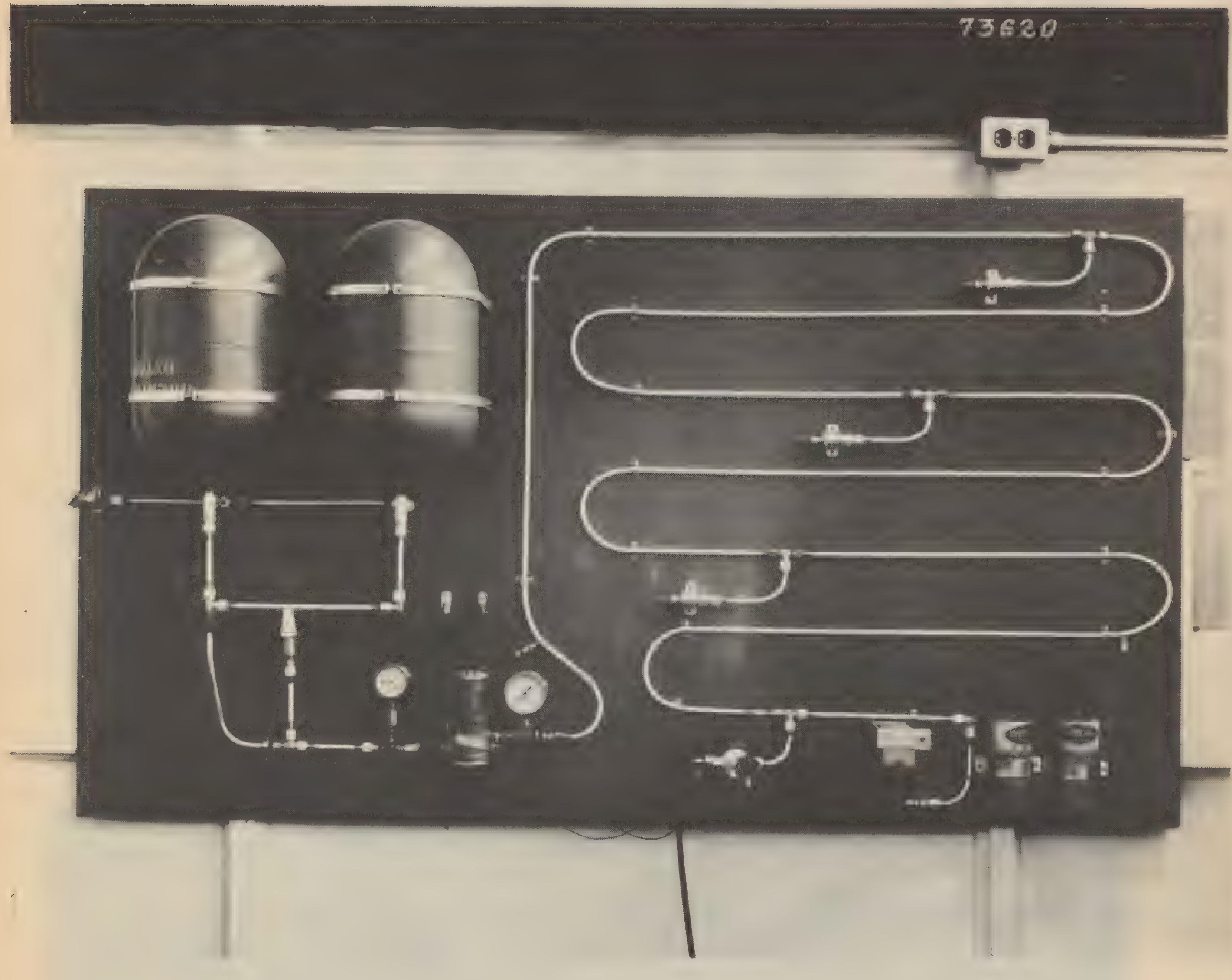


69345 Portable oxygen apparatus consisting of an assembly of standard items.

FIG. 15

73599 Aircraft oxygen cylinder recharger. Ground equipment for servicing low pressure oxygen systems.

FIG. 16



73620 Mock-up of low pressure oxygen system showing low pressure cylinders, filler valve, check valves, relief valve, automatic regulator, outlets for connecting masks, and experimental flow indicators.

FIG. 17

THE MECHANICAL EFFECTS OF HIGH ALTITUDES

ON THE HUMAN ORGANISM

The discussion thus far has been primarily concerned with deleterious effects of high altitudes caused by a lowered partial pressure oxygen in the inspired air. In the next few sections we shall consider high altitude disturbances exclusive of this, which, for want of a better term, are included under the general heading of the Mechanical Effects of Lowered Barometric Pressure.

Aeroembolism

One of the most outstanding of the mechanical effects is that produced by rapid ascent to high altitudes. Under these circumstances, certain gases which are normally dissolved in the blood may become liberated in the form of bubbles and interfere with the circulation. The cause of the bubble formation is due to the fact that the gases dissolved in the body fluids at ground level pressures exist in a state of supersaturation at the decreased pressures of high altitudes and bubbles begin to form in a manner similar to those in a bottle of charged water when the cap is removed.

Inasmuch as any object in the blood which tends to obstruct the flow is known as an embolus, the term aeroembolism has been selected to designate this phenomenon. This is to distinguish it from a disturbance of similar nature and cause occurring as a result of a rapid reduction of increased pressure during ascent from deep sea dives and in caisson work, which is known as "compressed air illness" or more popularly as the "bends".

In addition to appearing in the blood, bubbles may also form in the tissues and tissue fluids throughout the body, the most common sites being in the joints and fatty tissues. The symptoms vary in nature, depending on the location and amount of bubbles produced, the most frequent forms appearing as itching of the skin, dermititis in the form of a red macular rash, and pain ranging from slight to unbearable. Experiments have shown that probably four factors are concerned in the production of symptoms: (1) rate of ascent; (2) the altitude attained; (3) the time remaining at the altitude; and, (4) an individual susceptibility. Investigations in the low pressure chamber have further revealed that under 30,000 feet very few symptoms occur regardless of the rate of climb except in peculiarly susceptible persons. Above this altitude, symptoms may occur at rates of climb as low or even lower than 2,000 feet per minute with various degrees of intensity and at various times after reaching the altitude. The disturbance may occur within 10 to 15 minutes or may be delayed an hour or more.

Once the symptoms have developed immediate treatment is imperative. This procedure simply consists of returning to a lower altitude as rapidly as possible. It has been found that the majority of the symptoms usually disappear in the vicinity of 25,000

feet. The obvious way to cope with the situation is two fold in nature. First, select personnel who are not particularly susceptible to aeroembolism. As yet, the only way of determining this is by actual experience at high altitude or by predetermination in the low pressure chamber. The exact proportion of such persons among flying personnel is as yet unknown but an estimate of 90% would appear conservative. The second method would be one of prevention and for this purpose three procedures are available. First, the ascent can be made at a sufficiently slow rate that the dissolved gases will be eliminated gradually from the lungs without the formation of bubbles. This procedure is the simplest but may markedly interfere with tactical maneuvers. The second method is to wash out a great portion of the dissolved gases by breathing pure oxygen on the ground prior to ascent. The third and probably best method of prevention is through the use of the pressure cabin airplane in which rapid changes of barometric pressure do not occur. There is some possibility of aeroembolism occurring in crew members of pressure cabin airplanes, flying at high altitudes, upon complete loss of pressure.

73635 Exterior view of Low Pressure Chamber showing controls and instruments.

FIG. 18

EXPANSION OF GASES

Another manifestation of the mechanical effects of low barometric pressures are symptoms arising from the expansion of gases within the various cavities of the body. A fundamental gas law is expressed by the relation $PV = RT$ or $V = RT/P$ which shows that the volume of any gas is inversely proportional to the pressure exerted upon it. Table 2 shows the comparative volumes of gases at various altitudes.

The stomach and intestinal tract normally contain a variable amount of gas which is always maintained at a pressure approximately equivalent to that of the atmosphere surrounding the body. Therefore, during ascent these gases will tend to expand in direct proportion to the decrease of atmospheric pressure and will increase their volume at various altitudes as shown in table 2.

The effect of this expansion of the gastro-intestinal gases will vary somewhat according to the quantity of the gases present initially and also according to the rate of ascent. In the average normal individual an ascent of 200 to 300 feet per minute or less will result, beginning at about 12,000 to 16,000 feet, in a feeling of moderate abdominal distention. At this point there may be belching and an urge to pass flatus.

As ascent is continued, the above effects tend to persist for as the expelled gas is eliminated, it is replaced volumetrically by the expansion of the remaining gas and this process repeats itself until the ultimate altitude has finally been reached. At this point gas will continue to be expelled intermittently for an hour or two until that remaining has reached a volume approximately equivalent to that which it had initially at sea level after which the abdominal distention disappears and the abnormal belching and passing of flatus will no longer occur.

During ascent at higher rates of climb such as at 1,000 feet per minute or more, the effect is somewhat different. In this instance the gas tends to stay localized in pockets in the intestinal loops instead of moving downward and being passed off. As a result, the abdominal distention is increased considerably and at 15,000 to 20,000 feet altitude or above, one may begin to suffer from abdominal cramps of varying severity. At 30,000 to 35,000 feet these cramps almost invariably occur and if the gas tends to move along the intestinal tract at all it travels very slowly and at those high levels the abdominal cramps tend to persist for a period of several hours. In the mild cases, descent may relieve the distress but in severe cases it is not unusual for the cramps to last several hours after descent to sea level pressure.

The abdominal distention causes a variable amount of pain but has not been observed to seriously embarrass heart action or respiration in healthy subjects. However, it is believed that such distention would prove to be a distinct hazard to individuals who

were in poor health, especially those with lesions of the heart, lungs or gastro-intestinal tract.

It goes without saying that gas forming foods such as beans should not be ingested prior to a high altitude flight.

Expansion of gases within the sinuses and cavities of the head frequently produce severe pain and headaches during ascent to high altitudes. As is generally known the nasal accessory sinuses are mucous membrane lined, air filled cavities in the bony skull which open separately into the nose by means of patent openings. Experimentally it has been found that if these openings are normal, air will pass into and out of the sinuses without any difficulty at any practical rate of ascent or descent. However, if these openings are obstructed, pain will result due to the pressure differential between the air within and without the cavities. The frontal sinuses are most frequently affected, the maxillaries rarely, and difficulty with the ethmoids or sphenoids has never been observed. In contradistinction to the middle ear, the sinuses are equally affected by descent and ascent and when obstructed will cause agonizing pain over the affected area which will persist until the pressure differential is relieved. The treatment of these cases should be directed to the obstructed orifices which can usually be opened by shrinking the nasal mucous membranes with those preparations normally used for that purpose. If this treatment should fail to bring relief, it indicates that congestion of the nasal mucous membrane about the opening of the affected sinus is not the cause of the obstruction. In this event, search should be made to determine the presence of tumous, polyps, scar tissue or other growths about the sinus openings into the nose. In professional flyers, the necessary procedures should be instituted to assure free ventilation of obstructed sinuses for failure to do so will result in pain during flight and might, in some cases, lead to a chronic infection.

TABLE 2

The Comparative Volumes of the Gastro-intestinal Gases at Various Altitudes.	
Altitude	Relative Gas Volume
feet	
0	1.0
7,744	1.5
17,962	2.0
27,452	3.0
33,705	4.0
38,389	5.0
42,151	6.0
45,352	7.0
48,230	8.0
51,058	9.0
52,909	10.0

NOXIOUS GAS IN AIRCRAFT

The presence of noxious gases in aircraft compartments has been almost completely eliminated by modern construction methods, nevertheless, in view of the extreme toxicity of carbon monoxide at high altitudes it is considered necessary to briefly discuss this potential danger, since concentrations of carbon monoxide which are harmless at ground level become dangerous at high altitudes. In order to understand why this condition exists it will be necessary to give a short resume of the mechanics of carbon monoxide poisoning.

The deleterious effects of carbon monoxide on the human organism are the result of a dual action of this gas on the blood, thereby producing a state of anoxemia, the nature and effects of which have already been discussed. In the first place, carbon monoxide combines with the hemoglobin in the blood in a similar manner to that of oxygen, but the affinity of hemoglobin for carbon monoxide is 300 times as great as for oxygen, so that in the competition for a place in the hemoglobin molecule, the odds are 300 to 1 in favor of the carbon monoxide to the exclusion of oxygen. This in itself would be bad enough but the carbon monoxide already present in the arterial blood acts to further increase the anoxemia by preventing the liberation from the blood in the tissues of that amount of oxygen that does succeed in getting in. Hence, the extraordinary intensity of the anoxemia caused by combination of carbon monoxide with a given proportion of hemoglobin. Therefore, our concern about carbon monoxide poisoning at high altitudes is fully justified when one realizes that even a small loss in the oxygen carrying power of blood already impoverished of this gas due to low barometric pressures is likely to produce the dangerous symptoms of acute oxygen lack.

The blood saturation attainable with various concentrations of carbon monoxide in the inspired air and the resultant ultimate effects are shown in Figure 19. It will be noted that headache is one of the first symptoms to appear so that all cases of violent headache should be carefully watched.

The symptoms of carbon monoxide poisoning are generally known and vary with the carbon monoxide content of the blood as shown in Table 3. Table 4 shows the effect of various concentrations of carbon monoxide in the inspired air at ground level. It will be noted that it requires 0.04% to produce the first symptoms. Figure 20 shows the effect of carbon monoxide on arterial saturation at various altitudes. Assuming that the dangerous effects of oxygen want become manifest at an arterial hemoglobin saturation of 80%, these curves show that with no carbon monoxide in the air this point is reached at 14,000 feet. A similar condition with 0.005% carbon monoxide and 0.01% carbon monoxide occurs at 11.600 and 7,000 feet respectively, thus as little as 0.005% carbon monoxide lowers the altitude by 2400 feet while 0.01% reduces it to half its value in pure air.

In aviation the only logical method of dealing with this problem is to eliminate carbon monoxide from the cabins and cockpits of aircraft. The onset of carbon monoxide poisoning is so insidious and its effects so disastrous that preventive measures are the only ones to be relied on. While it is desirable that no carbon monoxide be present in aircraft, in single engine airplanes this is often impossible to accomplish and there are always traces of the gas present. In this situation it is necessary to establish the allowable concentration of gas which is harmless and which can be measured by practical methods. At the present time the best method is The Mines Safety Appliance Company indicator which can measure no lower than 0.003%. Since this concentration is within the limits of safety at altitudes up to the point at which oxygen should be administered, it is believed that 0.003% should be adopted as the maximum allowable in airplanes.

In testing aircraft for carbon monoxide, readings should be made at different throttle and mixture settings at different altitudes and with various cabin and ventilator openings. When any changes in the exhaust system, ventilating system, or where any new openings in the fire wall or fuselage are made, a new series of carbon monoxide tests should be made.

In cases of suspected carbon monoxide poisoning a 10 c.c. blood sample should be obtained at once since the carbon monoxide is washed out of the blood when pure air is breathed. The blood sample should be preserved anaerobically and analyzed by the Van Slyke technique.

Effect of Breathing Pure Oxygen

In connection with the breathing of oxygen, the question is sometimes raised concerning the harmful effects of this procedure. Oxygen can produce an irritation of the lungs if breathed over a sufficiently long period of time at high partial pressures. However, since such conditions do not occur in air travel, no harmful symptoms can result from breathing pure oxygen.

TABLE 3

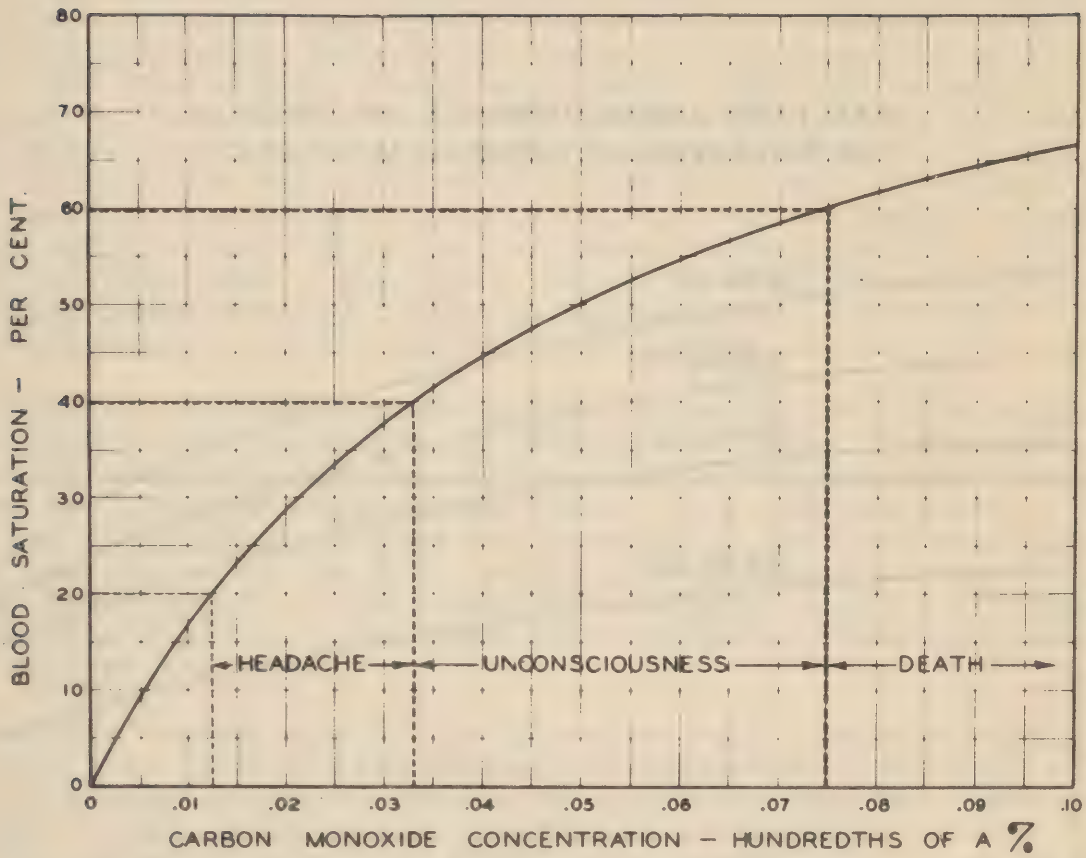
Symptoms developed with various concentrations of carbon monoxide in the blood

Per Cent Carbon Monoxide in Blood	Symptoms
0-10	None
10-20	Tightness across forehead, possibly slight headache, dilatation of cutaneous blood vessels
20-30	Headache, throbbing in temples
30-40	Severe headache, weakness, dizziness, dimness of vision, nausea and vomiting, and collapse
40-50	Same as previous, with increased pulse rate and respiration, and more possibility of collapse
50-60	Syncope, increased respiration and pulse, coma with intermittent convulsions, Cheyne-Stokes' type of respiration
60-70	Coma with intermittent convulsions, depressed heart action -- possibly death
70-80	Weak pulse and slowed respiration, respiratory failure and death

TABLE 4

Dangerous Concentrations of Carbon Monoxide

CONCENTRATION	EFFECT
0.01 per cent, or 1 part in 10,000	No symptoms for 2 hours
0.04 per cent, or 4 parts in 10,000	No symptoms for 1 hour
0.06 - 0.07 per cent, or 6 to 7 parts in 10,000	Headache and unpleasant symptoms in 1 hour
0.10 - 0.12 per cent, or 10 to 12 parts in 10,000	Dangerous for 1 hour
0.35 per cent, or 35 parts in 10,000	Fatal in less than 1 hour



Blood saturation and resulting symptoms produced by various concentrations of carbon monoxide in the inspired air.

FIG. 19

EFFECT OF CARBON MONOXIDE ON ARTERIAL HB SATURATION AT VARIOUS ALTITUDES.

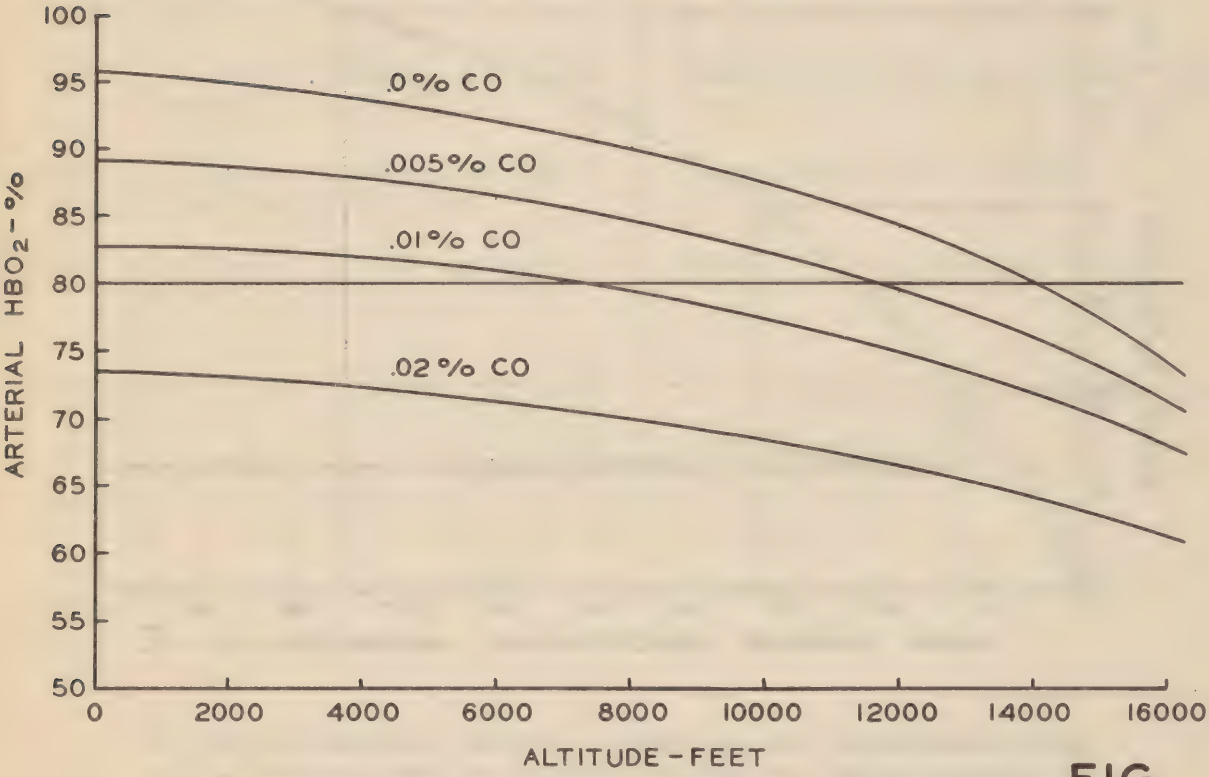


FIG. 20

THE EFFECT OF FLIGHT ON THE MIDDLE EAR

We now come to one of the most frequent of the mechanical influences of reduced barometric pressures which is the effect of flight on the middle ear. Those familiar with aviation medicine are well aware that airplane pilots suffer more frequently from disturbances of the middle ear then from all other occupational diseases combined. The disturbance occurs when the air pressure in the inner ear fails to equalize with that of the surrounding atmosphere. Pressure equalization in the ear is brought about through the eustachian tube which connects the inner ear with the throat. The tube which is only a potential tube and normally closed may be voluntarily opened by swallowing, yawning or other similar acts. Failure to open the eustachian tubes during the changes in altitude during aircraft flights is most frequently due to ignorance of the necessity to do so, but may be due to carelessness, to being asleep, from the influence of analgesics or anesthetics, or from coma. The first two of these instances usually occur among inexperienced pilots and passengers, the third on sleeper airplanes, and the latter on ambulance planes.

Inability to ventilate the middle ear voluntarily is much more prevalent than is generally recognized. Some of the most frequent causes of eustachian stoppage are acute and chronic infections of the upper respiratory tract, nasal obstructions, sinusitis, tonsillitis, tumors and growths of the nose and nasopharynx, paralysis of the soft palate or superior pharyngeal muscles, enlargement of the pharyngeal or tubal tonsil, inflamatory conditions of the eustachian tube following adenectomy and malposition of the jaws.

When for one or more of the above reasons, pressure equalization fails to occur during changes in barometric pressure, a number of painful symptoms occur. This disturbance has been named aero-otitis media which may be defined as an acute or chronic traumatic inflammation of the middle ear caused by a pressure difference between the air in the tympanic cavity and that of the surrounding atmosphere. It commonly occurs during changes of altitude in airplane flights and is characterized by all degrees of congestion, inflammation, discomfort and pain in the middle ear and may be followed by a temporary or permanent impairment of hearing. The disturbance is experienced much more commonly during descent than ascent due to a valve-like action of the tube.

While trained pilots usually try to avoid flying during periods when they have acute infection of the upper respiratory tract because of the discomfort and pain in the ears which almost invariably occurs, nevertheless, a considerable amount of such flying has been done. It might naturally be expected in these cases that during descent the intermittent blasts of air from the pharynx to the tympanic cavity would carry with it infectious

material to the mechanically irritated parts and readily set up an acute inflammatory process.

With respect to prevention, those who take up aviation as a profession should be carefully tested for patency of the eustachian tubes. Candidates examined during periods of acute infection of the upper respiratory tract should be reexamined after the infection has subsided before a final decision is made.

Prior to and during the flight the most useful prophylactic measure in normal cases is proper instruction of the individual concerned. As long as the patency of the eustachian tube is under voluntary control, there is no reason why trouble should arise. A simple explanation of the functioning of the eustachian tube followed by instructions as to how, when, and how frequently to ventilate should suffice. Probably the simplest maneuver to actuate the normal eustachian tube is to swallow. Chewing gum aids in this respect. This may also be accomplished by yawning, shouting, auto-inflation or by contracting certain muscles in the back of the throat, a procedure which may be effected by practicing the suppression of a yawn.

Those who are suffering from either temporary or permanent narrowing of the eustachian tubes should refrain from flying except under controlled conditions of gradual changes of altitude through a maximum range not to exceed 2,000 feet. Those with an acute infection of the upper respiratory tract who insist on flights should be prepared by gargling with a hot salt solution or by having a detergent spray directed well back into the nasopharynx followed by the installation or inhalation of atropine, ephedrine or benzedrine compounds. Recently the use of a mixture of helium and oxygen has been advocated to prevent painful ear symptoms, the idea being that the superior diffusion characteristics of helium would permit a more rapid equalization of the pressures in the ear. As the result of a series of carefully controlled experiments in this laboratory, it was found that this procedure was only about 5% effective and did not warrant the additional trouble and expense involved.

The prophylactic treatment described above is about all that can be done medically to eliminate difficulties with the middle ear during flight in our present aircraft. It should be obvious that this treatment is far from satisfactory and that it is approaching the problem from an improper standpoint since the anatomy of the ear cannot be modified to adapt it to flight. In this circumstance it is necessary to modify aircraft design to adapt it to the ear and this can be done by means of the pressure cabin airplane which provides a more or less constant pressure thus eliminating completely the problem of the painful ear.

In untrained subjects where the pain may become unbearably severe, the treatment during flight consists of a return to higher levels if possible until the pain is relieved, followed by a slow rate of descent. Methods of after treatment of injured ears are known to most Flight Surgeons, to whom flying personnel so afflicted should report.

OXYGEN WANT

In airplane ascent the cause of the deficient oxygen supply for the body, and hence its oxygen want, is the decrease in the partial pressure of the oxygen in the atmosphere. The oxygen percentage of approximately 20.93% remains the same but on a weight basis a given volume of air at high altitude contains less oxygen. We might state that there has been a molecular dispersion of the oxygen (and other gases) due to the decreased barometric pressure. A breath then of given amount at 30,000 feet would contain fewer molecules of oxygen than a breath of the same volume at sea level. As the ascent in an airplane continues, an altitude is reached at which the partial pressure of oxygen in the atmosphere is so low that consciousness cannot be maintained and life cannot be supported.

As is well known to all experienced flying personnel, there is an initial zone from ground level to approximately 8,000 feet where there is little appreciable physiological or psychological effect despite the fact the flight has been over a number of hours. The pilot sitting at rest is quite comfortable but a crew member exercising at even 8,000 feet may become breathless. Breathlessness upon exertion at high altitude is quite characteristic but does not occur to an appreciable extent in a person at rest.

In the zone from 8 or 10,000 feet up to 15,000 feet rather marked breathlessness occurs on exertion, and even in the man at rest the pulse rate is decidedly increased and breathing is increased in depth and possibly slightly in rate. These altitudes are compatible with a fairly high rate of mental performance if the period of exposure does not exceed several hours. Upon prolonged flights at 15,000 feet mental depression, loss of finer judgement, and dulling of the intellect will probably occur even in those who are young and physically fit. In other words, there is a partial adjustment to these altitudes, but it is not a complete compensation and undesirable effects occur, especially in the mental sphere. The longer the exposure the more pronounced will be the unfavorable effects.

Above 15,000 feet the ill effects of the oxygen want become more manifest in a shorter period of time until an altitude is reached when almost immediate unconsciousness occurs. The adjustment to altitudes above 15,000 feet varies considerably among individuals depending in part on physical fitness. However, it is always incomplete and malfunction is the inevitable result in the pilot who is exposed to altitudes of 15,000 feet or above for a short time.

Oxygen want can arise from disturbances in the supply of oxygen and its utilization. The former is almost entirely the case in aviation. It is well here to introduce the term "anoxia" because of its common use in aviation medicine. By anoxia is meant oxygen want or oxygen lack, and by it we mean any condition in which the normal processes of oxidation in body tissues are interfered with.

Acute oxygen deprivation may be followed or accompanied by a chain of symptoms depending upon the degree of anoxia and the duration. In general, the more rapid the development of the anoxia, the more likely are the effects on the central nervous system to precede those on the heart and circulation. If anoxia develops gradually during a number of hours, and is not too severe, the nerve tissues appear to adapt themselves somewhat and the subject retains consciousness as long as his circulatory system will stand the strain. Rapidity of oxygen withdrawal therefore favors predominance of central nervous symptoms, while weakness of the heart and lack of physical fitness favors preponderance of circulatory effects such as fainting, dizziness and pallor.

The effects of reducing the oxygen tension at varying rates may be described as follows:

a. When pure nitrogen is breathed, unconsciousness does not result until after 60 to 80 seconds have elapsed. This delay depends on the reserve of oxygen in the body. This reserve is in part held in the blood and in part in muscles. Unfortunately, nervous tissue has the poorest provision for oxygen storage. Heart rate and ventilation rate increase. Recovery is immediate.

b. When the oxygen content of the air is lowered gradually over a period of 30 minutes until breakdown occurs, about half of the subjects so exposed faint and half lose consciousness without fainting.

c. When the oxygen tension is lowered over a number of hours there is often a well defined sequence of events ensuing:

   1. Excitement or exhilaration.

   2. Depression, headache, even nausea and other symptoms of malaise.

d. If anoxia develops slowly over a period of days acclimatization occurs. However, if the changes are too great for adaptation, there results a gradual physical deterioration. Complete acclimatization can occur after some weeks at 17,500 feet but not above that limit.

The effects on the body, insofar as we know them, of varying durations of anoxia of different degree are:

a. Momentary anoxia, even the most complete, is followed by practically instantaneous recovery without after effect if normal oxygenation is at once restored.

b. Anoxia of fairly moderate degree if prolonged for one or several hours is followed by headache and malaise. These symptoms would appear to be due to cumulative changes which occur in the tissue cells.

c. When the degree of anoxia is too great for permanent toleration even though the onset is gradual, loss of weight, of strength, and of vigor occur.

The functional effects of anoxia have been described in the section on Respiration and Circulation, but will again be given. Every organ and tissue of the body is affected by anoxia, but the respiratory, circulatory and nervous system effects have been most thoroughly studied and these effects are thus better known.

In brief, the circulatory and respiratory effects are:

a. Changes in respiration - increase in rate and depth, but near collapse and death - retardation occurs and eventually breathing stops.

b. Circulatory Effects.

   1. Blood pressure is maintained or increased until the arterial oxygen saturation of the blood reaches approximately 60%, when it begins to fall.

   2. Minute output of the heart maintained or increased until about 60% saturation of arterial blood, when it falls.

A vicious cycle sets in when arterial oxygen saturation gets to 50 - 60% with the respiratory-circulatory apparatus becoming less efficient until death occurs. In unfit persons and in those with diseased hearts the vicious cycle sets in sooner.

The effects of anoxia on the nervous system are clearly recognized by investigators but are quite dangerous and insidious because even the most pronounced mental symptoms usually cannot be observed by the person affected because of the loss of the power of self-analysis and introspection. Between the altitudes of 10 and 16 thousand feet, most persons are less capable of clear reasoning and show a disinclination to perform mental tasks spontaneously. When the anoxia is more severe, sane judgement, discrimination, ideation, restriction of the field of attention, partial loss of emotional control with personality change, tremor and loss of coordination occurs. Changes occur in the eyes in that the illumination appears to be low, the muscle balance is affected and dark adaptation is impaired. Hearing becomes less acute and there may be a loss of awareness of the propellor and motor sounds. When the anoxia is quite severe, and prior to the onset of unconsciousness, a subject may sit glassy-eyed, immobile, inarticulate and unresponsive to ordinary stimuli.

A study of human behavior under anoxia and under alcoholic intoxication has caused many investigators to describe them as being very similar. With small doses of alcohol or moderate anoxia there may be a loss of inhibition characterized by exhilaration, unusual cheerfulness or joviality, lack of emotional control and slight loss

of coordination. With more severe anoxia or a larger dose of alcohol there is apt to be apathy, dulling of all intellectual functions, drowsiness, and loss of animation and gross incoordination.

It has been shown that anoxia can be a factor in air sickness and muscular fatigue and was thought, in some instances, to play a role in the nervous breakdown of some pilots in the last war.

Oxygen deprivation has been shown to cause an increase in the permeability of the capillaries resulting in the loss of circulating fluid to the tissues. This then causes an edema or "water-logging" of some of the tissues and may account for the headache after periods of anoxia on the basis of swelling of the brain tissue. Non-fatal anoxia, if prolonged and severe, may be followed by degenerative changes in the nervous tissues with resultant mental aberrations or minor paralysis. While it is well to remember the statement of Barcroft, the English physiologist, "Sever anoxia not only stops the machine but wrecks the machinery", there are no substantiated instances of permanent damage from anoxia among pilots.

It is obvious that oxygen want in a member of a combat crew in flight is an extremely undesirable occurrence. The pilot under such circumstances may commit a fatal error, the gunner may fail to protect the aircraft from hostile attack, and the mission cannot be completed with full success.

The solution of the problems presented is to supply each member of an airplane crew, flying at any altitude in excess of 10,000 feet, with adequate oxygen; he must know how to use his oxygen equipment efficiently; carelessness must be avoided; and, finally, he must have enough insight into the physiological problems to realize the necessity for these steps.

AIR SICKNESS

Air sickness must be differentiated from altitude sickness in both name and characteristics. Air sickness has little to do with oxygen want but is similar to sea sickness in that it is due principally to overstimulation of the labyrinth (organ of balance in the internal ear). Altitude sickness depends on anoxia.

Air sickness occurs very rarely in some people despite very rough air or even during violent acrobatics in the air. On the other hand there are many unfortunate persons who become air sick every time they go on a flight. It is obvious that individuals so afflicted are unsuitable as flying personnel in any flying capacity.

For the sake of brevity, air sickness and altitude sickness are compared or contrasted in the following table:

Table 5

	Air Sickness	(Anoxia) Altitude Sickness
Occurrence	Occurs at low altitudes where air is rough and turbulent or during maneuvers of the plane.	Occurs only at higher altitudes where air is apt to be smoother but oxygen pressure is lowered.
Persons involved.	Is most apt to occur in novices or those giving a history of sea sickness, train sickness or swing sickness.	Occurs in all persons repeatedly when flying without oxygen at higher altitudes.
Causes	Overstimulation of labyrinth of internal ear, psychic factors such as fright and anticipation, visceral sensations from abdomen, abnormal spatial orientation and visual references, and from less well defined stimuli such as odors of gasoline, burned oil, vibration, etc.; all caused by motion, in all planes, of the aircraft.	Due primarily to oxygen deprivation.
Symptoms	Yawning, belching, salivation, abdominal discomfort, nausea, vomiting, headache, malaise, distaste for flying, retching, sweating, and disinclination for any activity.	Rapid pulse, increase in ventilation, lowered mental capacity, exhilaration followed by apathy, loss of judgement, loss of coordination, and fainting or unconsciousness.

	Air Sickness	Altitude Sickness (Anoxia)
Treatment	Allay apprehension. Repeated aerial experiences have proven helpful. Attempt to remain in the center of gravity of the airplane where motion is least. Maintain adequate ventilation of cabin or cockpit. Busy oneself with some activity or mental concentration which seems to be of aid. Cease aerial maneuvers or seek strata where air is less turbulent, if possible.	Insure an adequate oxygen supply at all altitudes in excess of 10,000 feet. Above 33,000 feet, approximately, anoxia is bound to occur unless pressurized equipment is used.

FAILURE OF OXYGEN SUPPLY AND THE POSSIBILITY OF PARACHUTE ESCAPE AT HIGH ALTITUDE

The physiologic problems of flight have become more extensive and complex because of the great advances being made in aeronautic engineering and the corresponding progress in development of airplane power plants. The ceiling of aircraft now undergoing test is about 37,000 feet with the ability to maintain normal flight at slightly lower altitudes. Further developments in speed, rate of climb, speed of descent, maneuverability and ceiling can well be anticipated with war as the major impetus.

In the event of complete failure of the regular supply of oxygen at 35,000 feet with the aircraft intact a precipitant dive and plunge earthward would involve several hazards. An altitude of 18,000 to 20,000 feet would have to be reached within approximately a minute to one and a half minutes to prevent unconsciousness. This then would entail a vertical descent of at least 15,000 feet in one and a half minutes, or about 10,000 feet per minute. Structural strain of the aircraft would have to be considered because the angle of descent would, of necessity, be very acute and the speed of descent high. There would be a constant increment in speed in descent which would be greatest at the end of descent and either cause a greater centrifugal effect at the pull-out or force the pilot to increase his angle of glide, thereby taking more time. Pilot error, manifest by too abrupt leveling of flight with its resulting strain on the aircraft, might also occur as a result of anoxia. The black-out due to cerebral anemia produced by an abrupt leveling of the plane would probably also be more severe than usual because of the pre-existing anoxia. Injury to the middle ear and tympanic membrane might well occur but could not be considered other than of secondary importance.

There is another consideration, however, of the greatest importance, and that is escape from the aircraft when it has become seriously damaged or afire at high altitude. The rate of descent of a man of average weight with an open parachute is about 1200 feet per minute at ground level. In the substratosphere (35,000 feet -- Bar. 179) where the atmosphere is less dense, the rate of fall would be more rapid and would average about 2160 feet per minute. At 30,000 feet the rate of descent with an open parachute would be about 1,980 feet per minute, at 25,000 feet about 1,800 feet, at 20,000 feet about 1,620 feet per minute, and at 15,000 feet about 1,500 feet per minute. If then the crew escape from the plane at 35,000 feet and the parachute is opened rapidly it would require somewhat less than ten minutes to reach 20,000 feet by which time the parachutists might have succumbed to anoxia.

However, it would be possible to descend to 20,000 feet from 35,000 feet in approximately one minute in a free fall or delayed parachute opening.

A delayed parachute opening with a free fall of 15,000 to 18,000

feet would be a highly hazardous procedure because of the rather exact timing involved, and because the aviator might be somewhat anoxic and fail to pull the rip cord. The anoxia in this instance would probably be due to the fact that the aviator had to spend a little time in getting out of the plane and about a minute in descent, the amount of time spent in escaping from the plane being the critical time interval.

If a delayed parachute opening descent were the only alternative open to airplane crews in dire emergency there might well develop among aviators a distaste for high altitude missions and a lowering of the morale throughout flying commands.

With these two considerations in view, it would appear that the solution at present lies in the supply of an accessory emergency oxygen unit for each individual of an airplane crew flying at high altitude. A ten minutes' supply of oxygen is believed to be adequate as an emergency source because in this time the parachutist would have reached, or the intact plane could have been brought down, to altitudes at which the partial pressure of oxygen would support life.

PILOT FATIGUE

Fatigue is associated with weariness, inefficiency, weakness and disinclination to continue the provocative task. It has been thought by some that the sense of fatigue was a protective mechanism or warning that undue stresses were being imposed upon the body. However, it has been shown that the subjective sensation of fatigue is not a true criterion of the capacity of the muscles to perform physical work and under emotional stress the ability to work may decline without an occurrence of the sensation of fatigue.

It would appear that fatigue, with its diminution in the capacity to perform work, is primarily centered in the central nervous system although there may be a considerable fatigue component in the muscles.

The fatigue of flying personnel is occupational in character and is usually classified as "industrial fatigue". Fatigue of this type is incurred by emotional stress, mental effort and by varying amounts of physical activity.

Flying is a rather hazardous occupation and cannot be divorced from depressing emotions such as anxiety and fear. The amount of emotional stress is dependent upon the psychic makeup of the individual and the type of flying; whether in combat or peace, day or night, and good or adverse weather.

The environmental conditions of flying are unusual for terrestrial beings and the aircraft itself is a foreign abode. The plane travels at unusual speeds in the three dimensional planes. It is associated with odors of unusual character; the noises and vibrations are of unusual magnitude and frequency; the temperature and ventilation are usually not in comfort zones; transitions of position and changes in temperature, light and pressure are rapid; and spatial orientation requires effort. Unusual mental concentration is required of the pilot and most of the cranial nerves are being stimulated to an unusual extent. The eyes rove over the instrument control panel constantly. The ocular accommodation is being shifted frequently as the eye leaves the map or control panel to look at distant terrain. The nerve of equilibrium is being constantly stimulated by spatial changes resulting in showers of impulses being sent to the brain and to the muscles by associated pathways. There are myriad of impulses reaching the brain from the viscera due to minor shifts in their position within the abdominal cavity with postural changes. It is evident that these stimuli occur in normal everyday life but the magnitudes, complexity, constancy and multiplicity of the stimuli in flight are unusual.

The prevention and amelioration of fatigue in flying personnel is receiving a great deal of consideration by both the medical and engineering professions. The cockpits in aircraft are more comfortable and attempts to control the temperature and ventilation are being made. Engines are being made more reliable as are accessory

devices, and multi-engine aircraft capable of sustained flight with one or more engine failures are being utilized to a greater extent. Automatic pilots, radio compass, better communication facilities, excellent meteorological service, sound proofing, landing aids, and numerous other mechanical devices are of value in lessening the task and hazards of flying.

From the standpoint of personnel it is apparent that the initial selection of stable and rugged individuals will lower the incidence of staleness and provide personnel who are normally, at least, resistant to stress and strain. Young men are more resistant to the ill effects of fatigue and recover more quickly than older men, assuming a state of good health for each. Excellent health and physical fitness are very important factors in the consideration of resistance to fatigue and in the rapid recovery from fatiguing experiences.

It is well to remember that some degree of fatigue after a day's work is a usual occurrence and has no unfavorable effects since it will pass off quickly. However, fatigue may become cumulative (staleness) if the work is difficult and arduous, the hours of duty too long, and the conditions under which the work is carried out too unfavorable. Under these conditions an individual reduces his capacity for work and may impair his health.

In flying personnel, then, care in selection, age, state of health, physical condition, mode of life, rest and recreation as well as flying duties are important considerations in their efficiency and resistance to fatigue.

THE EFFECTS OF HEAT AND COLD ON THE BODY, INCLUDING A CONSIDERATION OF PROTECTIVE FLYING CLOTHING

Man is able to maintain a relatively constant body temperature (37°C ± 1.5°C) under a wide variety of environmental conditions. To do this it is necessary to maintain a balance between heat gain by the body and heat loss from the body. This is accomplished by the heat regulatory center in the brain which is quite sensitive to variations in body temperature and which serves to control the various physiological mechanisms which will produce alterations in heat gain or heat loss.

Before attempting a detailed discussion of the operation of the heat regulatory center it seems advisable to describe the various mechanisms or ways by which the body may gain or lose heat.

A. Heat Gain and Chemical Regulation of Body Temperature.

1. Metabolism or heat produced in the body as the result of combustion or oxidation of the food in the processes which keep the body alive and active is by far the most important source of heat gain which we need consider. Heat production being the result of chemical reactions is spoken of as the chemical regulation of body temperature. The rate of heat production when the body is in a reclining and fully rested condition (and 12 to 18 hours after the last meal) is known as the basal metabolic rate. The rate of heat production will be different if measured under conditions different from those stipulated above, but, of course, cannot then be called basal.

   a. Effect of exercise or work on heat production. Even the slight amount of exertion required to maintain the body in a sitting position increases heat production 10 to 20% above the basal rate. Moderate exercise, such as walking, may raise the heat production to twice the basal rate and extremely hard work or exercise may increase it to 10 or 15 times the basal level. Shivering is a form of exercise consisting of the involuntary contraction and relaxation of certain groups of muscles in the body and may raise metabolism to 4 or 5 times the basal rate. This is one of the most effective mechanisms which the body possesses for increasing heat production and maintenance of a constant body temperature under cold environmental conditions. Intense mental effort increases metabolism only a very slight amount.

   b. Effect of ingestion of food on metabolism. Heat production begins to rise within an hour after food is eaten, reaches a maximum increase of 10 to 30% above

basal about the third hour and is maintained at this level for several hours. This increase is due to excess energy needed to digest and assimilate the food into suitable forms for use in the body. It is greatest when protein foods are eaten.

c. Effect of sleep on heat production. Heat production is decreased 10 to 15% below the basal level during quiet sleep. One scientist has suggested that the metabolic rate as measured during quiet sleep should have been termed "basal metabolism" since this is the lowest rate it is possible to obtain in the normal individual. The decreased heat production during sleep is one reason why sleep should be avoided when exposed to a cold environment. Freezing and death will occur more rapidly.

2. Other modes of heat gain by the body. Some heat may be gained by the ingestion of food or drink which is hotter than body temperature and by radiation from hot objects outside the body but under ordinary circumstances these are of minor importance as compared with metabolism. However, heat absorbed by the body when exposed to the sun's rays on a hot summer day may be as much as 5 or 6 times as much as the basal heat production rate.

B. Heat Loss and Physical Regulation of Body Temperature.

Since heat loss from the body is dependent almost entirely on physical factors, it is spoken of as the physical regulation of body temperature.

1. Radiation, Convection, and Conduction. Heat loss by radiation is dependent upon the temperature difference between the body surface and surrounding objects. In hot weather or when surrounding objects are above body temperature, the body will gain rather than lose heat by radiation. Heat loss by radiation may be diminished by the use of clothing.

Heat loss by convection is dependent upon the temperature difference between the body surface and the surrounding air and upon the rate of movement of the air over the surface of the body. This mode of heat loss may also be decreased by the use of clothing.

Heat loss by conduction plays only a small part in body temperature regulation.

2. Evaporation.

a. From the respiratory tract. The air we breath is usually relatively dry when inhaled but becomes saturated with water vapor at body temperature while in

the lungs and is thus laden with moisture when exhaled. For every gram of water thus evaporated the body loses about 535 calories of heat.

b. From the skin surface.

1. Insensible Perspiration. This represents water lost from the skin due to diffusion of water vapor through the epidermis. It is a loss which is entirely independent of the sweat glands and remains fairly constant under a wide variety of environmental and physiological conditions.

2. Sensible Perspiration or Sweating. This water is brought to the skin surface via activity of the sweat glands and in terms of total heat loss may represent no loss at all when the body is cold and sweat glands are inactive; or 95 to 98% of the total heat loss on a hot day when the environmental temperature is 95°F. or above.

3. Heat Loss Due to Warming of Inhaled Air. Exhaled air has a temperature which approximates body temperature. The heat loss due to warming of this air is dependent upon the temperature of the air when inhaled. If air at 70°F. is inhaled, warming of this air will account for about 2 to 3% of the total heat loss. If air at -40°C (or F.) is inhaled, heat lost in this way will amount to 10 or 15% of the total heat loss.

4. Other Modes of Heat Loss. Heat loss due to the ingestion of cold food or drink and its subsequent excretion at body temperature may be included in this category.

Body Temperature Regulation.

The temperature regulatory center in the brain controls the principal modes of heat gain and heat loss so as to maintain a relatively constant body temperature under a wide variety of environmental and physiological conditions.

In a very warm environment or when additional heat must be dissipated from the body during work or exercise at ordinary temperatures, the regulatory center reacts by increasing the blood flow to the surface of the body and by stimulating the sweat glands to activity. The increased blood flow to the skin carries more heat to the surface where it may be lost by radiation, convection, or evaporation. In a hot environment (98°F. or above) no heat can be lost by radiation or convection, hence evaporation must account for almost all the heat loss. This can be done satisfactorily so long as the environmental air is not too well saturated. If the environmental air is both hot and saturated all modes of heat loss

are restricted and body temperature will rise resulting in heat stroke. Fortunately, the air is seldom fully saturated with moisture on a hot day and evaporation from the body can usually take place. However, the stifling discomfort of a hot environment when even moderately saturated (relative humidity of 50 percent to 70 percent) is not an uncommon or pleasant experience.

Heat stroke may result from disfunction of the sweat glands due to lack of water or salt in the body. Our sensations of thirst warn us of even a moderate water deficit in the body, but a salt deficit may exist without causing any undue sensation in the body. Salt being the chief inorganic constituent of sweat, it is possible in a hot climate when large quantities of sweat are secreted to deplete the body of its salt content to a point where the secretion of sweat is impaired. This impairment of the chief mode of heat loss under these conditions may result in an abnormal increase in body temperature and finally heat stroke. To prevent this condition, it is wise when large quantities of sweat are being secreted day after day to ingest a little salt with each drink of water. Some industrial concerns supply salt tablets at the drinking fountain for employees who work daily in a hot environment. This is a remedy which needs to be taken only in moderately extreme environmental circumstances and does not constitude endorsement of the popular notion that salt ingestion will enable one to stay cooler on a hot summer day.

To assist the temperature regulatory mechanism in maintaining a constant body temperature under extremely hot conditions, we usually decrease our activity as much as possible thus decreasing the rate of heat production. We may stay out of the direct rays of the sun thus decreasing heat absorption by radiation from the sun, and we may wear light clothing which will hinder as little as possible sweat evaporation from the skin. White clothing is preferable in summer as white will absorb less radiant heat from the sun and other objects than will colored or black clothing.

In a cold environment the temperature regulatory mechanism is faced with the problem of conservation of the heat produced by the body. To do this sweat secretion is stopped thus restricting the heat lost by evaporation to (1) the insensible perspiration which diffuses through the skin and (2) the evaporation due to saturation of inspired air in the lungs. Blood flow to the skin (especially in the extremities) is decreased, thus reducing skin temperature (Figure 21) and the temperature difference between skin and environment as much as possible. This reduces heat loss by radiation and conduction.

Under more extreme conditions when a heat balance can no longer be maintained by decreasing the heat loss, heat production may be increased involuntarily by shivering, or voluntarily by work or exercise.

We assist the body in maintaining heat balance in a cold environment by the use of clothing, which serves to decrease heat

loss particularly by radiation and convection. We adjust the quality and quantity of clothing roughly to the severity of the external conditions and the temperature regulatory mechanisms in the body continues to serve as the fine adjustor.

As mentioned before, conservation of body heat is effected by constriction and a decreased blood flow in the blood vessels of the skin and a consequent decrease in skin temperature. This effect is most notable in the extremities, particularly in the hands and feet (Figure 21). These areas are, therefore, the best thermostatic indicators of body temperature conditions. The decreased blood flow in these areas serves the essential and quite useful purpose of decreasing heat loss and enabling the body as a whole to maintain a heat balance. It also raises the minimum tolerable environmental temperature which these extremities can withstand without freezing. Actually the temperature of the foot when unprotected by clothing will come down as low as the environmental temperature (Figure 21) and sometimes even lower (due to evaporation of insensible perspiration). Freezing of inadequately protected feet may even occur without an appreciable reduction in the internal body temperature. Thus we see that a mechanism which acts for the best interests of the body as a whole in the maintenance of a constant body temperature may produce an effect which is detrimental to a specific part of the body under extreme conditions. The designing of clothing which will adequately protect the hands and feet under extremely cold conditions is probably the most difficult problem to be faced in heavy winter clothing design. It is made more acute in the Air Corps by the necessity for decreasing bulkiness and increasing tactility on the extremities, particularly in the case of the hands.

Another unusual problem which arises in connection with protective clothing in aviation results from the wide range of temperatures which may be encountered in any one flight, especially if high altitudes are reached. On the average there is a temperature decrease of 3.5°F. with each one thousand foot increase in altitude until a temperature of -55°F. is reached. Thus in going from sea level to 30,000 feet a flyer will encounter a temperature drop of approximately 105°F. (3.5°F. x 30), that is, he may go from a temperature of 70°F. on the ground to a temperature of -35°F. at 30,000 feet. Suitable clothing at one of these temperatures will obviously not be suitable at the other. This poses a difficult problem for the pursuit pilot or any other member of an airplane crew who cannot easily put on or take off clothing while in flight.

Maintenance of Heat Balance in Air Corps Personnel:

The solution to the problem of maintaining heat balance in flying personnel at low temperatures has progressed along three rather distinct pathways each of which has certain advantages and disadvantages.

A. One of these solutions involves heating of the cabin of the plane to a temperature at which the occupants can

maintain a heat balance and be comfortable when wearing ordinary clothing.

1. Advantages of this system:

   a. Heat can be adjusted as outside conditions change.

   b. Activities of personnel are not restricted by heavy clothing.

2. Disadvantages of system:

   a. Dependence of personnel comfort and efficiency on a heating mechanism which by practical experience is often subject to failure.

   b. No protection against cold for crew in event of forced landing and abandonment of ship on a cold terrain.

   c. Formation of frost on window surfaces hampers visibility. This has been proven by experience in the present war to be particularly undesirable and dangerous especially on high altitude bombing and combat missions.

B. Another solution involves the use of sufficient unheated insulating clothing to enable each crew member to reduce heat loss sufficiently to maintain heat balance.

1. Advantages:

   a. Independence of outside source of heat under all conditions, including forced landing and abandonment of ship on a cold terrain.

2. Disadvantages:

   a. Weight and bulkiness of clothing necessary to keep the body warm hampers activity of personnel (Figure 22). This especially concerns the hands which must be well protected and yet must perform numerous operations requiring tactile dexterity.

   b. Inability to adjust clothing worn to the amount required by the widely varying environmental temperature. This is most acute in the case of the pursuit pilot who must don clothing on the ground for protection against very low temperatures to be encountered at high altitude. Perspiration accumulates in the clothing at ground level temperatures making the garment most un-

comfortable and inefficient when cold temperatures are reached.

c. Difficulty of providing ventilation for evaporation of moisture (sweat or insensible perspiration).

C. The third solution involves the use of electrically heated clothing by each crew member for maintenance of heat balance and protection against extremely cold temperatures (Figure 23). Electrically heated clothing may be used in combination with varying amounts of insulating clothing.

1. Advantages:

   a. Heat can be adjusted to requirements necessitated by outside temperatures.

   b. Bulkiness of clothing can be reduced to a minimum or to a degree which will permit normal activity and efficiency of personnel.

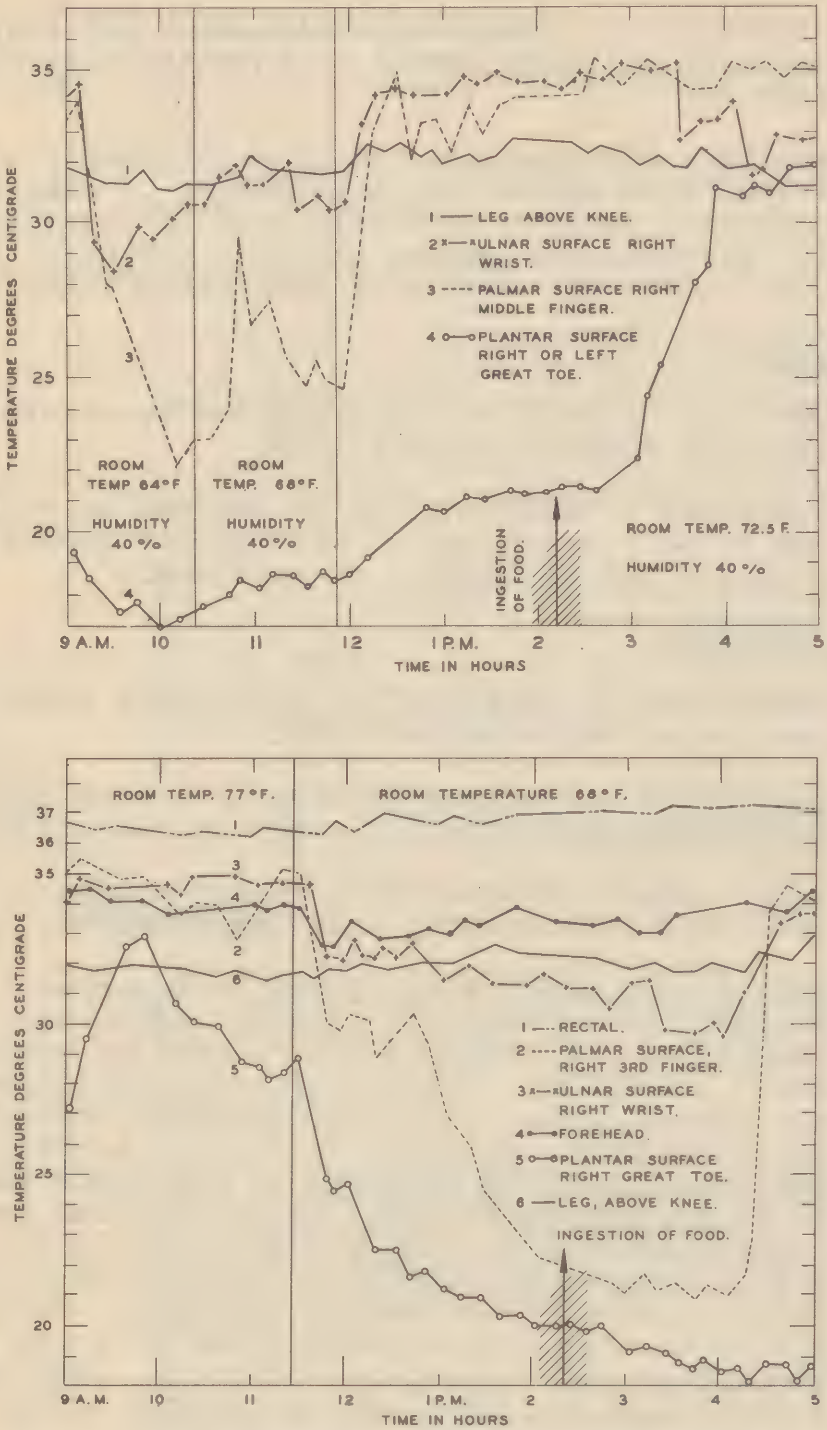
2. Disadvantages:

   a. Dependence of personnel on an outside source of heat which may sometimes fail.

   b. Inadequate protection in case of forced landing and abandonment of ship on a cold terrain.

   c. Large amount of electrical energy needed for each suit at extremely cold temperatures.

The final solution of the problem may possible incorporate the best features of the electrically heated suit with insulating clothing of maximum bulkiness commensurate with normal personnel comfort and efficiency. Insulating clothing of moderate weight (standard intermediate winter flying clothing) could be tolerated on all body areas except the hand, which is needed for tactile operations. Sufficient heat could be supplied to the hands and feet, and other areas if necessary, to keep the extremities and the body as a whole warm and comfortable. Heavy mittens could be carried as accessory or emergency equipment for protection in case of failure of the heating system or abandonment of ship. This would provide adequate protection independent of the ship for all except the most severely cold environmental conditions, such as those encountered at very high altitudes and in the far north.



CHANGES IN THE SKIN TEMPATURES OF THE LEGS, WRISTS, FINGERS, TOES AND FOREHEAD OF A NORMAL MALE, IN THE BASAL STATE, PRODUCED BY CHANGES OF ENVIROMENTAL TEMPERATURE, AND AFTER INGESTION OF FOOD. RELATIVE HUMIDITY 40 PER CENT.

(AFTER SHEARD ET. AL.)

FIG. 21

73335 - Experimental Down-filled Alaskan Parka and Trousers.
(note extreme bulkiness necessary for protection)

FIG. 22

73330 - U.S. Rubber Electrically Heated Suit designed to protect the wearer at temperatures down to -60°F. when worn next to the body and beneath ordinary street clothing plus light gaberdine coveralls. Type A-6 winter flying shoes should be worn over the shoes shown. No additional glove is required. A scarf and helmet will protect the neck and head.

FIG. 23